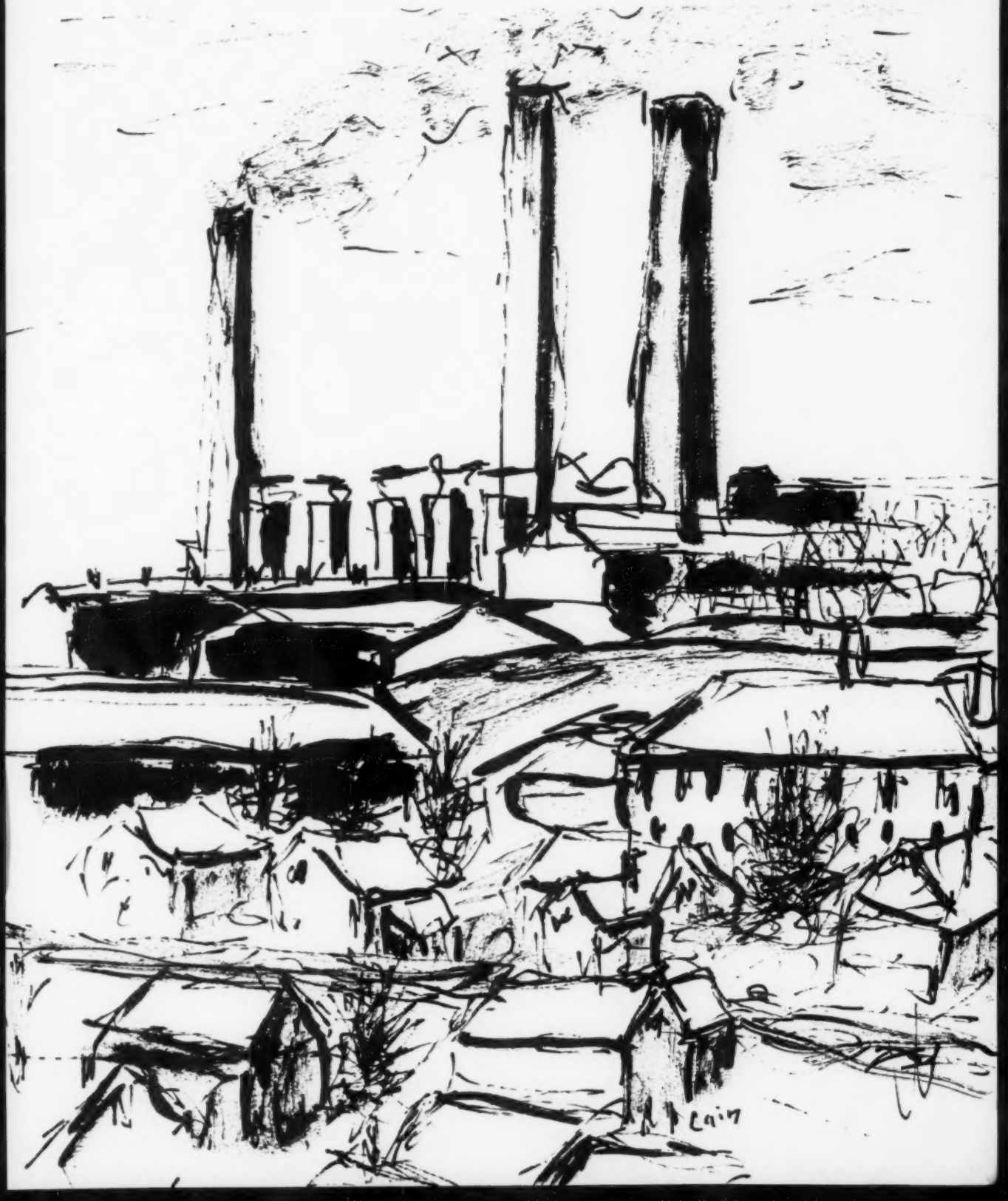
JOURNAL OF

METALS

MARCH 1960



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JOURNAL OF

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Vol. 12, No.3
March, 1960

COVER: Drawn by David Cain, this is one of the nickel plants discussed in four articles taken from the International Symposium on the Extractive Metallurgy of Copper, Nickel, and Cobalt of the 1960 AIME Annual Meeting. Operations in Oregon, New Caledonia, Cuba, and Canada are described beginning on p. 197.

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personnel

- These items are listings of the Engineering Societies Personnel Service, Inc. This Service, which cooperates with the societies of Civil, Electrical, Chemical Mechanical, Mining, Metallurgical, and Petroleum Engineers, is available to all engineers, members and non-members, and is operated on a nonprofit basis. If you are interested in any of these listings, and are not registered, you may apply by letter or resume and mail to the office nearest your place of residence, with the understanding that should you secure a position as a result of these listings you will pay the regular employment fee of 5% of the first year's salary if a non-member, or 4% if a member. Also, that you will agree to sign our placement fee arrangement which will be mailed to you immediately, by our office, after receiving your application. In sending applications be sure to list the key and job number.
- When making application for a position include eight cents in stamps for forwarding application to the employer and for returning when possible.

—MEN AVAILABLE—

All those listed under "Men Available" have membership in AIME.

Metallurgical Engineer; nine years research experience (nuclear and nonferrous materials). Solid-state bonding studies, project leader, ability to standardize, organize and cut project costs. Prefer New York or West Coast. M-222.

Sales Manager desired; BS Met Eng., age 28. Two years experience production supervision, quality, costs, ferrous metals; 1 year sales engineering, marketing, distributor relationships, customer contact, nonferrous metals. Prefer foreign or N. Y. Met. Area. M-223.

Metallurgical Engineer. Diversified experience, open pit mining, beneficiation, hydrometallurgy, pyrometallurgy, agglomeration. Several years top operating staff experience in large and medium size operations. Strong background organization, cost reduction and all phases of administration. Domestic and foreign experience. M-224.

Mill Superintendent; age 51, four years college in ore dressing. Many years experience as mill superintendent and consultant on silver, lead, copper, cobalt, tungsten, iron. $9600. Prefer West or any. Se-263.

Process or Physical Metallurgist; MetE, age 26. Three years experience in quality control and heat treating for nonferrous sand castings, foundry, and operation of pilot plant extraction for copper smelter. Two years instructor on fundamentals of electronics for Air Force. $7200. Prefer West, North Central US. Se-159.

Production or Management Engineer; MinE, age 41. Eighteen years experience mining mineral dressing in non-metallics, underground, open pit, all phases of mineral dressing, exploration, research and development, design and construction. Staff engineer background, costs, estimating and budgeting, reports. Desire production or engineering management position. $12,000. Prefer West Coast or any. Se-1740.

Consultant or Manager; MS Met E (Australia), age 52. Wide experience in all phases copper smelting and refining, electric furnace melting of copper, powder metallurgy, and so on. Also lead smelting and refining. $18,000. Prefer West or foreign. Se-1851.

Maintenance Engineer; ME (Germany), age 49. Experienced in ore processing plants, diesel power plants, heavy construction and mining equipment, diesel repair, heavy trucks and shovels, floating cranes to 300-ton capacity, and pipe-line construction. Administration of open pit mines, ore, iron and copper. $7200. Any US location, Se-151.

Superintendent; MinE, age 40. Seventeen years experience in charge of surface, underground, open pit mines and mills; uranium, zirconium, tungsten, lead, zinc, manganese, antimony. $8400. Prefer West, Southwest. Se-1821.

Superintendent; ChE, age 43. Twenty-five years experience nonferrous concentrating and hydrometallurgical operations, including duty as chief chemist, furnace superintendent, mill superintendent, spectrographer, surveyor, and chemist-assayer. Salary open. Prefer West. Se-1619.

Mill Superintendent; age 63. Twenty-two years experience as mill superintendent in charge of mill and research, treating manganese, lead, zinc, copper, gold, silver. Thirteen years charge of coal mining. Salary open. Any US location. Se-461.

Director of Research; ChE, age 47. Twenty-eight years experience as manager and director of research and development on mines and mills. $15,000. Prefer West. Se-104.

—POSITIONS OPEN—

Address replies for positions to the nearest local office of the Engineering Societies Personnel Service, Inc., *not* to the JOURNAL OF METALS. Offices are located at 29 E. Madison St., Chicago 1, Ill. . . . 57 Post St., San Francisco, Calif. . . . and 8 W. 40th St., New York 18, N. Y.

Metallographer; minimum B.Met.E. or B.S. Met. Advanced degree preferred. Location: Orange Co., N. Y. W8558.

Chief Metallurgist with 10 to 15 years experience in metallurgical field, preferably on fabricated product lines. To set up metallurgical laboratory and guide metallurgical problems in company's five plants. Will be responsible for setting material specifications and necessary test procedures for checking incoming material. Must have broad background. Equipment manufactured is of fabricated type—alloy steels, castings (ferrous), and forgings. Salary $12,000 to $15,600. Location: Mich. W8539.

Chemical or Metallurgical Engineer for pilot plant work on semiconductors and special metals. Salary $6000 to $7200. Location: N. J. W8522.

Metallurgist or Metallurgical Engineer with substantial experience in metallurgy. Should be acquainted with metals, heat treatment, and so on in all phases, preferably steel mill as well as manufacturing experience. Should also be capable of setting up metallurgical controls and heat treating methods, procedures, and so on . . . train and direct native personnel for plant fabrication and assembling trucks, buses, and automobiles. Duration, minimum 12 to 18 months. Location: Mexico. F8508.

Steel Research Metallurgist with advanced degree, preferably Ph.D. Also, at least 5 years melting practice closely allied with R & D programs; knowledge of laboratory electric steel melting techniques as applied to steel process studies and alloy development is essential, as is knowledge of methods of analysis, examination, and testing of experimental alloys. Must have major interest and capability in R & D, with an understanding of production problems. Will conduct research and development projects in alloy steels in a new modern laboratory. Apply by letter, including salary requirements. Location: Pa. W8492.

Engineers. a) Metallurgical or chemical engineer; graduate with about 5 years production experience in nonferrous smelting and refining fields. b) Assistant plant engineer; graduate with about 5 years plant engineering and equipment maintenance experience in nonferrous smelting and refining fields. Salaries, $8000. Location: New England. W8427.

Process Engineers. Mechanical, industrial, and metallurgical graduates to be responsible for the improvement of existing processes and equipment. Should be familiar with the economics of a mill's operation. Salaries open. Location: Conn. W8202.

Sales Engineer with at least 5 years machinery and equipment experience covering finishing and coating of ferrous and nonferrous strip. Various locations in East and Midwest. Salary $10,000, with bonus. W8175.

Metallurgist-Physicist for major producer of small-diameter tubing. Graduate metallurgist or physicist with minimum of one to two years experience, preferably in field of nondestructive testing. Participation will be in the development of eddy current methods, ultrasonic tests, and other instrument applications. Apply by letter, including salary requirements. Location: Pa. W8150.

Metallurgical Engineer to take charge of production and development experience in metallurgical vacuum casting, hot pressing, and so on. Salary high; opportunities good. Location: northern N. J. W8141.

Analysis Engineer; mechanical or metallurgical engineer with materials engineering and development experience on heat transfer equipment in power fields. Salary open. Company pays placement fee and relocation expenses. Location: upstate N. Y. W8131.

Junior Metallurgist with ore dressing background for mining operation. Location: East. W7967.

Research Metallurgist. Ph.D. in metallurgy with experience and evidence of having guided significant work in research metallurgy. Will conduct developmental projects and investigations in physical metallurgy, with only occasional supervisory direction. Salary $8000 to $11,000. Location: Pa. W8090.

Plant Metallurgist with at least 5 years open-hearth and steel mill experience. Salary $10,000 to $12,000. Location: East. W8311.

Estimator; MetE, or MinE, or Me with broad experience in heavy industrial construction and engineering estimates, preferably mining and mineral industry. Must be qualified to make project, budgetary, and appropriation estimates and be able to supervise small group. Salary and benefits. Location: West. Sj-4928-R (c).

Research Engineers. a) Fabricating research engineers; B.S., M.S., or Ph.D. in ME or Met E. Minimum six years experience in metal processing (press working, spinning, machining, chemical milling, and so on) with high-strength steels, titanium, and refractories. Some experience in research and development of metal fabrication processes and techniques desirable. b) Welding research engineers; B.S., M.S., or Ph.D. in ME or MetE. Minimum six years experience welding and/or brazing high-strength steels and refractories. Some research and development of metal joining processes and techniques desirable. c) Metallurgical Engineers; B.S., M.S., or Ph.D. in metallurgy or metallurgical engineering for metal processes of high-strength steels. $9000 to $15,000. Location: Northern Calif. Sj-4903-R.

Physical Metallurgist for development of aluminum alloys and fabricating practices. Salary commensurate with education and experience. Location: Northwest. Sj-5021.

A weekly bulletin of engineering positions open is available to AIME members at a subscription rate of $3.50 per quarter or $12 per annum; $4.50 per quarter or $14 per annum for nonmembers, payable in advance. Local offices of the Personnel Service are at 8 W. 40th St., New York 18; 57 Post St., San Francisco; and 29 E. Madison St., Chicago 1.

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The John Jay Hopkins Laboratory for Pure and Applied Science at General Dynamics' General Atomic Division in San Diego, California, is a modern center of research and development, where new ideas and techniques are vigorously pursued. Here, strong engineering and development activities are matched with broad basic theoretical and experimental research to create an ideal environment for productive efforts in the nuclear field.

Here, advanced work is underway on the High Temperature Gas-cooled Reactor (HTGR), which promises to be a major short cut to the nation's goal of economic nuclear power. The prototype HTGR plant will be constructed by 1963 for Philadelphia Electric Company and High Temperature Reactor Development Associates, Inc.

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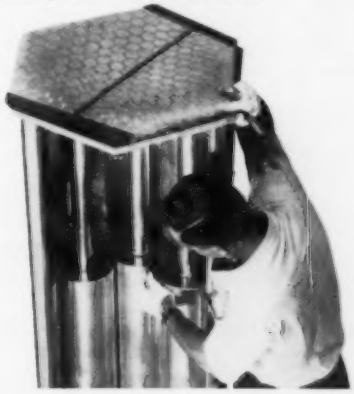
In the important area of metallurgy, immediate openings exist for experienced metallurgists and ceramists to investigate and solve the following types of problems . . . physical and mechanical properties of high-temperature materials and refractory compounds . . . high radiation and ultra high temperature-pressure effects on materials . . . reactor fuel element development and fabrication . . . fuel reprocessing . . . corrosion effects.

In addition to **Metallurgists, Nuclear Engineers, Mathematicians-Programmers**, and Experimental and Theoretical **Physicists** are invited to consider opportunities now existing in varied program areas. Please address your letter of inquiry to Manager of Personnel, P.O. Box 608-R5, San Diego 12, Calif.



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education

Research at NYU

► Metallurgical research at New York University's College of Engineering ranges from the study of Ti-Al phase relations to developing techniques for coating ceramic substrates with thin metal oxide films.

During 1959, research under the direction of Harold Margolin revealed the existence of a new phase in the Ti-Al system. In a parallel study, partial isothermal sections between 500° and 1400°C in the Ti-Al-Cr and Ti-Al-V systems have been delineated. Results have confirmed the phase relations of the binary Ti-Al diagram, and a better understanding of both systems has been achieved.

Dr. Margolin and his colleagues are also working on high-strength titanium alloys. Several alloys having an 0.1 pct yield strength under 190,000 to 205,000 psi have been developed. These alloys have impact strengths of 7 to 11 ft lb at —40°F and exhibit adequate tensile ductility.

Another study is determining the effect of small amounts of hydrogen on the embrittlement of titanium alloys. Using Ti-8Mn and Ti-6Al-4V alloys, hydrogen contents up to 750 ppm were found to have little or no deleterious effect on the ductility of the titanium-aluminum-vanadium alloy tested in stress rupture or in slow tension.

Rointan Bunshah is studying brittle fracture, martensitic transformations, and deformation processes. The study is utilizing ultra high-speed photographic techniques with exposure times of 10^{-7} sec. Dr. Bunshah is also developing high-strength, titanium-active eutectoid alloys for use at temperatures in the 1200° tp 1400° range.

Kurt L. Komarek is busy developing a method for measuring activities and thermodynamic qualities in aluminum alloys. Aluminum activities in a number of iron-aluminum alloys have been determined, and a negative deviation from Raoult's Law indicative of strong bonding has been established. Dr. Komarek's group is also studying reaction rates and products of graphite and high-refractory oxides in an effort to determine the controlling factor in these reactions.

Irving B. Cadoff heads a research group studying *chalcophytes*, a new class of polyatomic semiconductors. Melting points, Vickers hardness, and micro and macrostructures of the compounds $CuInTe_2$, $AgInTe_2$, and the alloy $Au_{.75}In_{.75}Te_{.50}$ have been determined and treated analytically. In addition, the thermoelectric power of the compounds has been determined over a temperature range of —196° to 550°C. The compound $CuInTe_2$, because of a positive Seebeck coefficient at all temperatures investigated, seems to be a promising positive element for thermoelectric generators.

Dr. Cadoff and his group are also continuing a study of the lattice expansion of selected hexagonal close-packed, high-purity metals, seeking new basic data on thermal expansion. The study, further, seeks a correlation between anisotropy of crystal structure and thermal expansion anisotropy in the hexagonal close-packed metal system, as well as a comparison of unit cell expansion and gross expansion of solid samples.

John P. Nielsen, chairman of the metallurgical engineering dept., is directing a study of techniques for coating ceramic substrates with thin metal oxide film. Since the coating of ceramic materials requires very intense heat, a solar furnace capable of temperatures in excess of 3000°C has been built. The furnace is being used for direct vaporization of oxides and the sintering of mechanically-coated materials. Using vapor deposition techniques, a method has been developed

(Continued on page 240)

J&L STEEL

RESEARCH METALLURGISTS

Continuing growth of the J&L research and development program has created a number of openings for professional personnel, holding Ph.D., M.S., or B.S. degrees in metallurgy or a related scientific field. Projects underway or in prospect cover a diversity of subjects in physical and process metallurgy, all of course, related to the production of carbon and stainless steels, and all company supported. Because of this diversity, it is almost always possible to accommodate individual interests. The J&L Research Division is housed in the modern, air-conditioned, fully-equipped Graham Laboratory in suburban Pittsburgh. Attractive residential areas are close by. And progressive Pittsburgh offers many advantages, including full graduate programs at the University of Pittsburgh and Carnegie Institute of Technology for the man who wants to continue his professional education.

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Interesting position open in the Metallurgy Department of a large industrial materials research laboratory for a metallurgical engineer with 3-5 years experience, preferably in high temperature work, to apply metallurgical principles to the development of cermet materials. Replies held in confidence.

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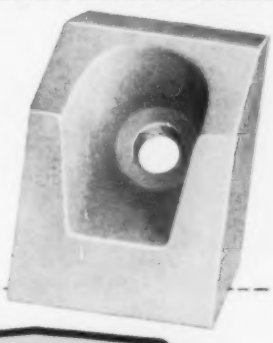

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new books

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The Physical Metallurgy of Magnesium and Its Alloys, by G. V. Raynor, *Pergamon Press Inc.*, 122 E. 55th St., NYC, 531 pp., $12.50, 1959—Author Raynor moves from a discussion of the fundamental nature of magnesium to its use in forming alloy systems. Magnesium's electronic constitution and the effects of alloying are also introduced.
Theories of solid solubility limits . . . . liquidus curves . . . intermetallic compound formation. . .and lattice spacing variations are presented in detail, with the interrelationships between intermediate phases shown. •

Proceedings of the First Symposium on Electron Beam Melting, *Alloyd Research Corp.*, 202 Arsenal St., Watertown, Mass., 100 pp., $1.50, 1959—The transcript contains 15 technical papers from the Symposium, plus summaries of 12 papers presented at a similar gathering in England this year.

AIME authors are among the contributors, including Stanley Abkowitz on *E-B Melting of Ti and Ti Alloys;* J. L. Orehotsky and A. J. Opinsky with *Electron Bombardment Apparatus for Zone-Melting of Tungsten;* H. W. Schadler, *Electron Bombardment Melting of Tungsten;* L. L. France, *Conversion of a Consumbale Arc-Melting Furnace To Electron-Beam Melting of Titanium;* and J. W. Pugh, *On the Purification of Tungsten by Electron-Beam Refining.*

Implication of Rhenium Research in The Design of Refractory Alloys is a memorandum derived from a talk given by R. I. Jaffee at the Symposium on Ultrahigh-Temperature Material in Indianapolis last year.

A great deal of study is now going on concerning this extremely scarce element in the hope that research will enable scientists to understand the metal's behavior, and ultimately reproduce it in refractory metals free of rhenium.

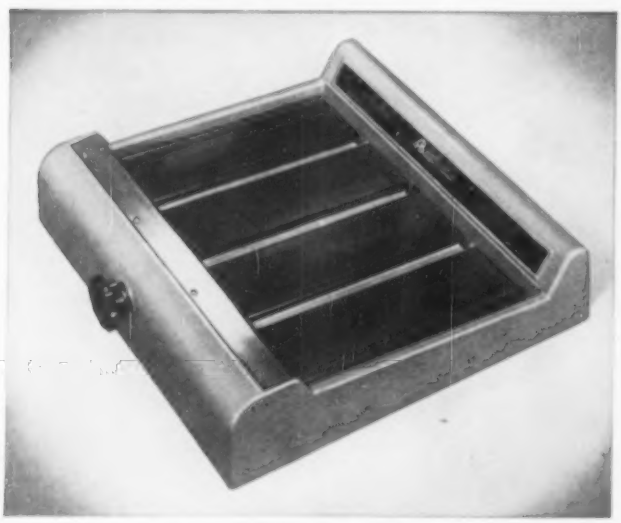
The metal is interesting in that it has a hexagonal close-packed crystal structure which melts at about 3100°C. Its elevated temperature strength is considerably higher than that of tungsten. Rhenium metal also has an exceptionally high rate of work hardening, and when added to molybdenum produces a body-centered cubic solid-solution alloy resulting in about 50 wt pct rhenium. Pure molybdenum fails to work with only a few ppm unless extrusion or some other means of providing lateral support for the grains is made. Combined with rhenium, the grain boundaries have a greater proportion of metal-to-metal contact compared to pure molybdenum.

The low-temperature ductility of the molybdenum-rhenium alloy is another of its unique features. Molybdenum-rhenium alloys show extensive mechanical twinning in tension or compression from —196°C to room temperature, and to a lesser extent, up to as high as 250°C. Adding 20 to 30 pct Re reduces molybdenum's interstitial content, lessens the locking of dislocations, and lowers yield strength and its dependence on temperature.

It appears that three effects of rhenium on molybdenum are responsible for its unique behavior. These are: oxygen redisposition, twinning, and unlocking of dislocations.

For special applications, as in material for vacuum tubes, electrical contacts, X-ray targets, and thermo-couples, it is hoped that rhenium-containing alloys will perform functions vital enough to

(Continued on page 178)



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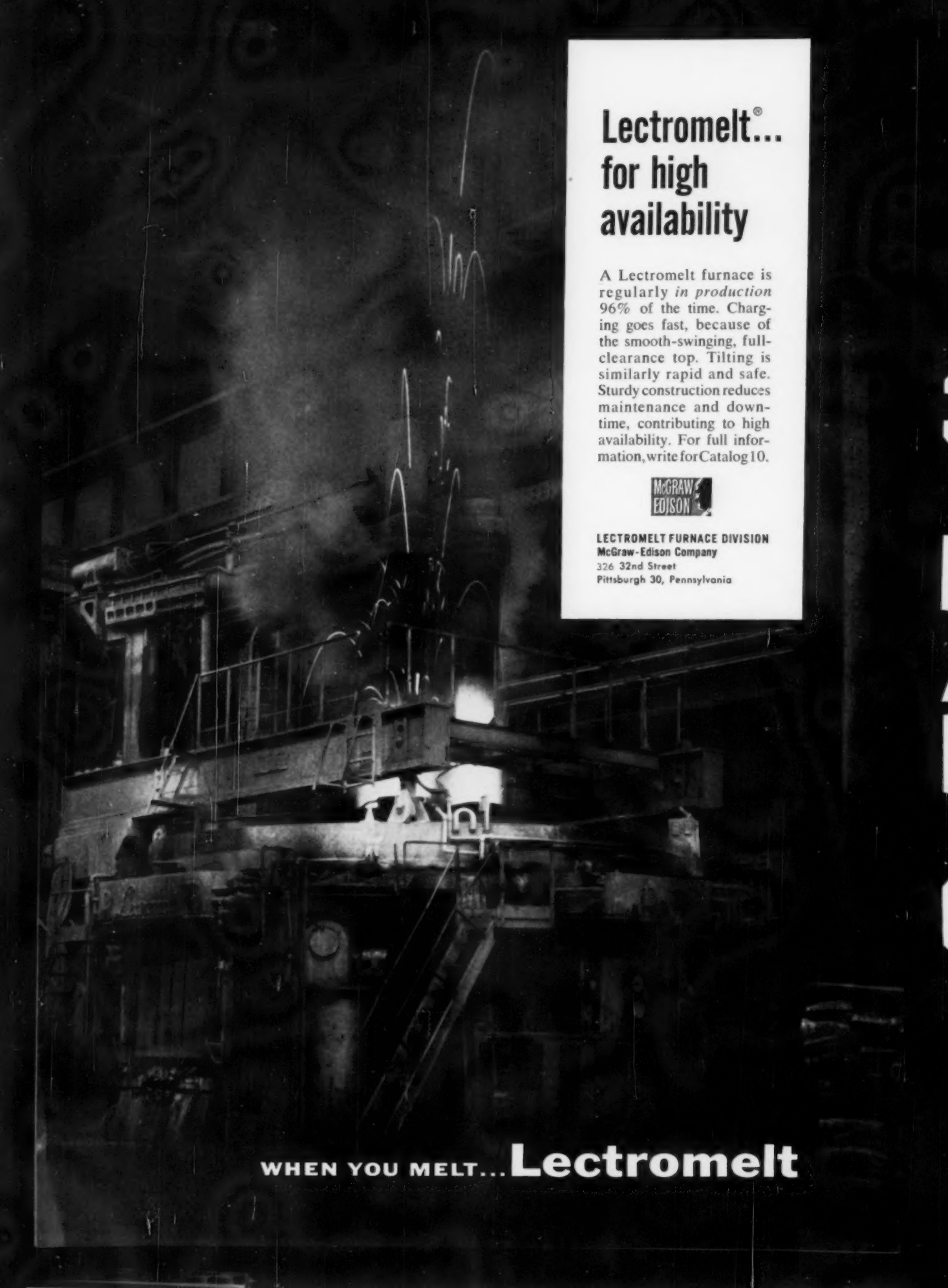

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Thermal Protection Systems: No single material possesses the range of complex properties necessary to withstand the high temperatures of missile and space requirements. To solve this problem, composite materials and structures that combine the desirable characteristics of several materials, are being developed. Some of these approaches include insulating layers and heat sinks; transpiration, film or liquid-metal cooling; ablation and sublimation coatings. Shown is an artist's rendering of an insulating, composite material made up of extremely thin layers of metal and ceramics which promises to be very efficient in protecting against high-heat environments. Development of such systems is considered at Lockheed to be an integrated relation of materials, environment and design.

METALLURGY

EXPANDING THE FRONTIERS OF SPACE TECHNOLOGY

Metallurgy is typical of Lockheed Missiles and Space Division's broad diversification. The Division possesses complete capability in more than 40 areas of science and technology—from concept to operation. Its programs provide a fascinating challenge to creative engineers and scientists. They include: celestial mechanics; computer research and development; electromagnetic wave propagation and radiation; electronics; the flight sciences; human engineering; magnetohydrodynamics; man in space; materials and processes; applied mathematics; oceanography; operations research and analysis; ionic, nuclear and plasma propulsion and exotic fuels; sonics; space communications; space medicine; space navigation; and space physics.

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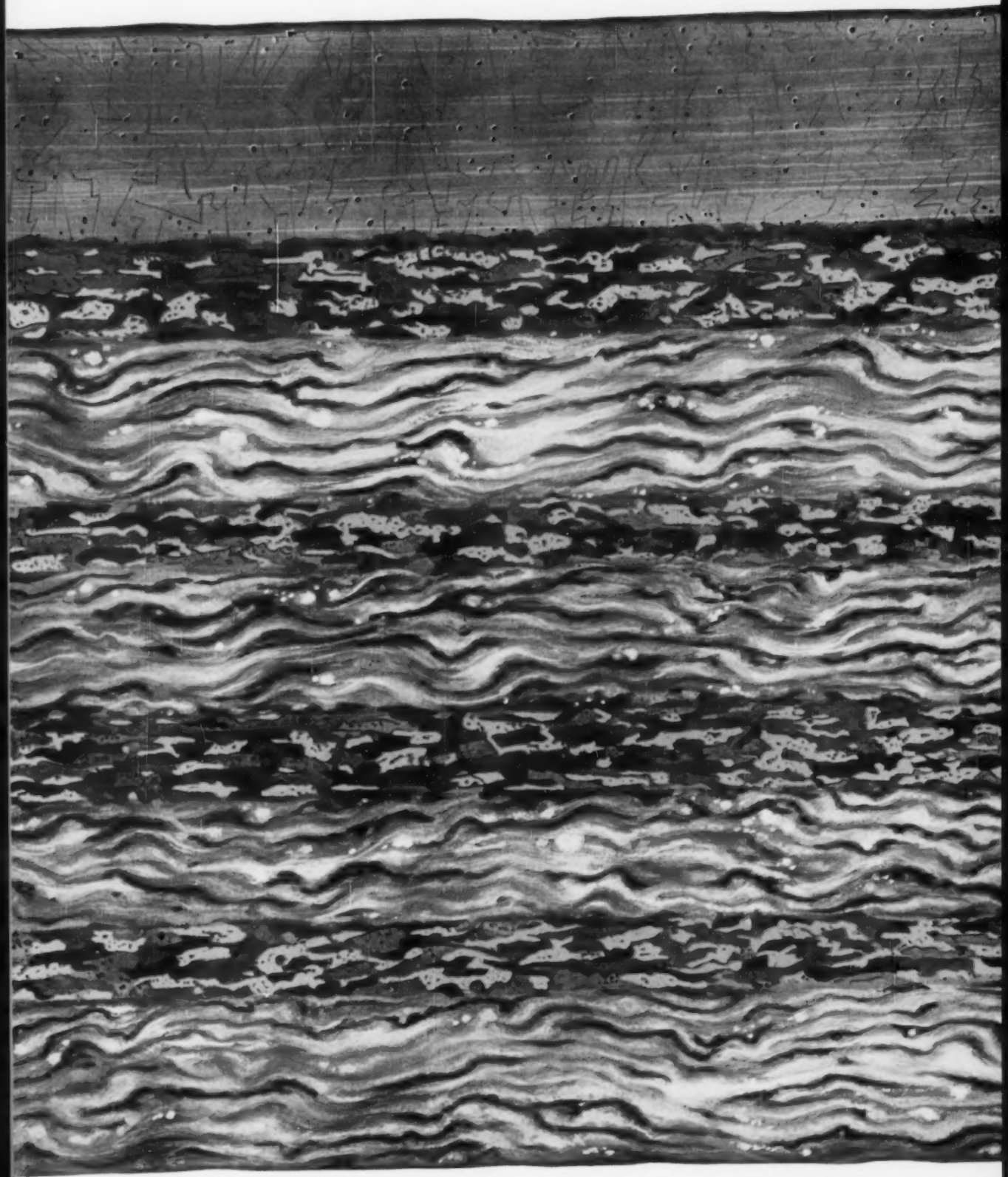

BOOKS

(Continued from page 174)

justify the effort put into their development.

Copies of the paper, labeled DMIC Memorandum 7, may be obtained through the *Office of Technical Services, Dept. of Defense, Washington 25, D. C.*

Rheology of Disperse Systems, edited by C. C. Mill, *Pergamon Press,* 223 pp., $9.50, 1959—Latest experimental and theoretical work in this field is covered in these papers, presented at a British Society of Rheology conference. The first category of papers deals with dispersions which are dilute or composed of non-interacting particles, the experiments being designed to test hydrodynamic theory. The second portion investigates concentrated suspensions in order to relate performance to rheological properties. •

The Magnetodynamics of Conducting Fluids, by Daniel Bershader, *Stanford University Press,* 145 pp., $4.50, 1959—Electromagnetic theory and fluid mechanics are combined from the continuum point of view in order to discuss the physical concepts and obtain results relating to the influence of magnetic fields on wave propagation, shock tube flows, subsonic and supersonic nozzle flows, and viscuous boundary layers. Although the studies are largely analytical, some experimental results dealing with magneto-hydrodynamic lift and with shock wave behavior have been added. •

Progress in Nuclear Energy (Metallurgy and Fuels, Vol. 2), edited by H. M. Finniston and J. P. Howe, *Pergamon Press,* 653 pp., $21, 1959—This volume is divided into two parts. Part one gives an accounting of the metallurgical development of various materials of specific interest to nuclear energy. An attempt is made to report the experiences of various countries in respect to their development of particular fuel elements for a number of reactor systems. Part two deals with solid state physics and physical metallurgy. •

Ionenaustauscher (Vol. I), by F. Helfferich, *Verlag Chemie,* 520 pp., approx. $11.50, 1959—This first of a three-volume German-language set on ion exchange covers the fundamentals: theory . . . structure and method of action . . . types of ion exchanges with their constition and properties . . . ion exchange membranes and packing towers . . . behavior in non-aqueous and mixed solutions . . . and special types of exchangers. Succeeding volumes will deal with specific applications. •

Metals for Nuclear Reactors, by W. A. Maxwell, *American Society for Metals,* 117 pp., $8, 1959—This basic introduction to the principles of nuclear metallurgy discusses physical principles; typical design and materials problems; effects of radiation; corrosion by liquid metals and aqueous solutions; fabricating techniques for reactor components; and testing methods. •

Modern Aspects of Electrochemistry. No. 2, edited by J. Bockris, *Academic Press, Inc.,* 416 pp., $13, 1959—Beginning with interionic attraction in solution, a field of renewed interest because of significant progress towards the theory of concentrated solutions, the papers included discuss the physical chemistry of ion-exchange resins, molten electrolytes, and the mechanism of anodic processes at electrodes. A recent branch of electrochemistry dealing with the semiconductor-solution interface is the subject matter of the final paper. •

The Structure of Metals, published for The Institution of Metallurgists, *Interscience Publishers, Inc.,* 118 pp., $4, 1959—Following a description of modern concepts of electron theory of metals, the experimental techniques which have been developed to test the theory are presented. Such factors as width of valence band, shape of the density of states curves, shape of Fermi surface, and the

(Continued on page 182)

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B.S., M.S., or Ph.D. in metallurgy or metallurgical engineering with experience in the field of metal processing or metal joining of high strength steels, titanium, and refractories.

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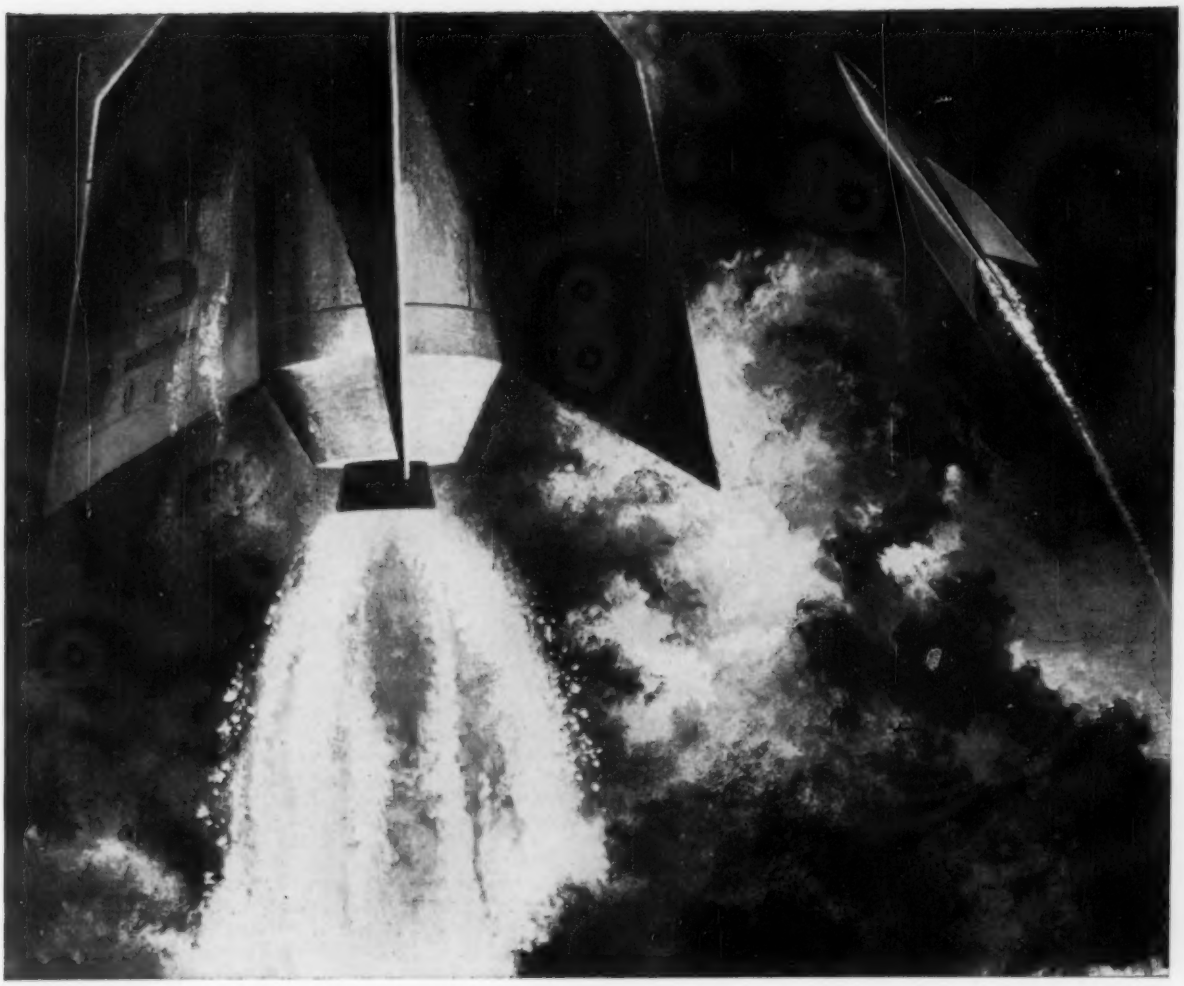

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BOOKS

(Continued from page 178)

number and signs of charge carriers in electrical conduction are noted. Dislocation theory of plastic deformation is also mentioned, and experimental techniques associated with it are described. The papers comprising the volume were given at The Institution of Metallurgists' refresher course in 1958. •

Proceedings, International Committee of Electrochemical Thermodynamics and Kinetics, 9th meeting, *Butterworth & Co.*, Canada, Ltd., 489 pp., $24, 1959—This collection of papers discusses thermodynamical data and potential, pH diagrams, electrochemical definitions, experimental methods in electrochemistry, batteries and accumulators, corrosion and protection against corrosion, electrochemical kinetics, electrochemistry of semiconductors, and modern electrochemical methods in analytical chemistry. The papers are written in French, German, and English. •

Herstellung Warmgewazter Feinbleche (Producing Hot-Rolled Thin Sheets), 2nd edition, by Ernst Günther, *VEB Verlag Technik*, Berlin, 326 pp., approx. $6, 1958—The arrangement of rolls, roll stands, and roll trains; the heating of sheet packs; and the rolling process are all covered in this German work. Special sizes and types of sheet are considered, and one chapter is devoted to mechanized installations. An appendix contains the German standards on thin sheets. •

High-Resolution Nuclear Magnetic Resonance, by J. A. Pople and others, *McGraw-Hill Book Co., Inc.*, 501 pp., $13.50, 1959—Emphasis is on aspects important to chemical applications, such as spectral analysis and the interpretation of chemical shifts. In the second part of the book application is made to molecular structure determinations, isomerism, conformational analysis, tautomerism, hydrogen bonding and other intermolecular effects, chemical equilbria, reaction rates, and chemical analysis. •

Nondestructive Testing Handbook, (2 vols.,), edited by R. C. McMaster for the Society for Nondestructive Testing, *The Ronald Press Co.*, $24, 1959—A glut of information has been synthesized to produce this guide to industrial process improvement and new engineering materials. The chief emphasis is on test techniques, principles, equipment, test suitability, and test interpretation. The judgments of a board of 106 contributing and consulting editors went into this two-volume study. The result is 54 co-ordinated sections of literature on nondestructive testing, including 1200 charts, drawings, and photos, plus graphs and tabular matter. •

The Metallurgy of Yttrium and the Rare Earth Metals, by B. Love for Wright Air Development Center, US Air Force, 188 pp. $3, 1959—This study was prompted because current technology offers a possibility of using scandium, yttrium, and the rare earths in advanced weapons systems. This investigation includes metallographic, oxidation, and corrosion resistance studies; mechanical property determination; and studies of titanium and beryllium with rare earth additions. Improved methods for the production of the pure metals are described, and a complete metallographic procedure is developed. Procedures for the chemical and spectrographic analysis of metals and alloys are provided, including a method for oxygen analysis. Order *PB 151825* from the *Office of Technical Services, US Dept. of Commerce, Washington 25, D. C.*

Thermodynamics, Part II of Chemical Process Principles, by O. A. Hougen, K. M. Watson, and R. A. Ragatz, *John Wiley & Sons, Inc.*, 1072 pp., $9.75, 1959—This book continues the intensive quantitative training in the practical applications of physical chemistry to industrial problems and the prediction of physicochemical data from generalized principles begun in the first volume. Through recent developments in thermodynamics and kinetics, these principles have been integrated into procedures for process design and analysis with the objective of arriving at optimum economic results from a minimum of pilot-plant or test data. Fundamental principles of thermodynamics are presented with particular attention to generalized methods. The applications of these principles to problems in the compression and expansion of fluids, power generation, and refrigeration are discussed. However, a treatment of the mechanical or equipment problems is not attempted. •

Practical Design of Sheet Metal

(Continued on page 186)

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RESEARCH METALLURGIST is sought as group leader. Doctorate degree required or record of technical achievement. Several years of industrial experience desirable but not necessary, in either ferrous or non-ferrous metallurgy. The job requires planning of research programs directed toward the use of lithium and manganese in metallurgical applications; phase diagram studies; physical and mechanical properties of alloy systems; chemical properties of alloys. Salary open. Location East. Box 4-JM.

METALLURGISTS

To work in research and development on projects concerned with new or improved products or processes. Involves metallurgical development work in the laboratory and pilot plant stage. Interest in both ferrous and non-ferrous metals important. Send resume and salary requirements to J. A. Turner, John A. Roebling's Sons Division, The Colorado Fuel and Iron Corporation, 640 So. Broad St., Trenton 2, N. J.

Metal powder output aired

A total of almost 35,000 tons of iron powder was consumed last year, according to the Metal Powder Producers Assn., trade division of the Metal Powder Industries Federation. This figure includes both domestically-produced powders and imports. In 1958, the total was about 22,500 tons, lower than normal because of general business conditions. Kempton H. Roll, Executive Secretary of the Association, declared that 1959 iron powder consumption would have been still higher if it had not been for the steel strike.

Imports apparently have reached a low plateau, and most likely will remain between 500 to 750 tons per year. Shipments during 1959 were at an all-time high, reaching their peak in the second quarter with an average of almost 3500 tons per month during that period. In the fourth quarter the average was closer to 2600 tons-per-month, with the highest rate in December.

Of the major iron powder consuming industries, structural parts manufacture represented the greatest percentage, with almost 54.5 pct of the total. Welding electrodes and flame cutting applications represent the next highest consuming industry at 36 pct. This is the first time that structural parts applications have exceeded, to a substantial degree, the consumption of iron powder by other markets, and is a strong indication of the growth of powder metallurgy parts use in home appliances, business machines, automobiles, and so on.

Electronic and magnetic applications for iron powder increased during 1959, representing 4.5 pct of the total. The remaining 5 pct consumed represents friction materials (also higher than 1958), pharmaceutical iron powders, seed cleaning powders, and so on.

The capacity for producing iron powder in the US and Canada alone—completely disregarding import potentials—is almost three times as great as the current market for iron powder, according to a survey conducted by the Association.

Nonferrous metal powders also reflected an overall market growth during 1959. Copper and copper-base powder, both flake and granular, reached a high of about 25,000 tons, according to the Copper Division of the Business and Defense Services Administration.

The total available domestic capacity for the production of all types of copper and copper-base powder is about 34,000 tons per year—well in excess of the demand. The survey was conducted among all nonferrous powder producers by the Metal Powder Producers Association.

Thus, it appears that both iron and copper-base powders will continue to be in good supply for the immediate and foreseeable future.

Combine LD, Kaldo use

The Consett Iron Co. Ltd., has announced plans for a new plant which will bring together LD and Kaldo oxygen steelmaking processes for the first time. Head Wrightson Iron & Steel Works Engineering Ltd., in cooperation with Pintsch Bamag AG, Cologne, Germany, has been assigned the job of building the two 100-ton LD units and the two 100-ton Kaldo units which will be installed. The plant is expected to go into production at the end of 1961, and is designed to produce 750,000 tons annually.

According to T. Olof Dormsjo, Stora Kopparberg Corp., "Consett decided to adopt both processes to obtain effective cover for its range of products. It is my understanding that mainly low-carbon steels will be made in the LD furnaces, while Kaldo will handle medium-, high-carbon, and special grades."

The International Construction Co., Ltd., is acting as consulting engineers for the project. "International Construction is also consulting for the Oxelosund plant in Sweden with two 100-ton furnaces," Mr. Dormsjo advises. "This plant will go into operation towards the end of this year, while in France the Sollac plant, according to latest advice, is somewhat ahead of schedule and may start initial operations with the 100-ton Kaldo furnace after the middle of this month."

Nickel consumption up 25 pct

Free world consumption of nickel during 1959 exceeded 400 million lb—about 25 pct over the 320 million lb consumed in 1958—says Dr. John F. Thompson, Chairman of the Board, The International Nickel Co. of Canada, Ltd.

"Despite the prolonged steel strike in the US," he continues, "nickel consumption in that country in 1959 registered an increase of about 35 pct over 1958. Marked gains in nickel consumption were also recorded in the UK and other European markets. The US, as in the past, was again the world's largest consumer of nickel.

"Free world capacity for nickel production in 1959 was at an annual rate of about 550 million lb from all sources," Dr. Thompson points out. "This capacity, based on presently planned programs, is expected to increase by more than 10 million lb, or 18 pct, in the next two years.

"Canada continues to be by far the largest supplier of nickel to the US, the UK, and other free world markets. Of the free world's present operating capacity for nickel production, Canada accounts for over 70 pct; Cuba, 10 pct; US, 4 pct; and New Caledonia, Japan, and other sources, the remainder.

REPORTER

REPORTER

Heat-ac electricity conversion

The first successful conversion of heat directly into alternating current electricity in significant amounts has been reported by scientists of General Dynamics Corp.'s General Atomic Div. Researchers at the division's John Jay Hopkins Laboratory for Pure and Applied Research used a high-temperature cesium cell converter in producing alternating current sufficient to illuminate a series of small light bulbs. The current is not in the conventional frequency range of 60 cycles, but rather in the high range of 100 kilocycles, frequently used for radio transmission.

The cesium cell is said to simultaneously produce both alternating and direct current. And the cell can be made into shapes practical for atomic power reactors.

Cesium is also finding use in an ionic engine operated by the Lewis Research Laboratories of the National Aeronautics and Space Administration. Using cesium as a propellant, scientists have surmised that an ionic engine such as this could be applied to space craft after they have gone outside the earth's atmosphere. J. H. Childs, head of the Cleveland laboratory, said the engine would have low fuel consumption—about 1/1000 lb per hr for 40 kw output.

W alloy performs at 1750°F

A new high-temperature alloy containing 13 pct tungsten is performing successfully in jet engines at up to 1750°F. The alloy, known as WI-52, is being used for turbine nozzle vanes in the Pratt & Whitney J-57 engine that powers the Bo-707 and DC-8. It was developed by Stanford Research metallurgists under a research contract for the Tungsten Institute. The new alloy supplants its predecessor X-40—in use since 1941—which has an operating peak of 1600°F. WI-52 is said to give more thrust per pound of engine . . . decrease fuel consumption . . . and lengthen engine life. Protective coatings of chromium and aluminum have also been developed to offset the oxidation which occurs at about 1750°F.

High-strength steel made

Unimach UCX2 is the name given a new high-strength steel developed for high-performance rocket motor cases for missiles. The Universal-Cyclops Steel Corp. development is a modification of AISI 4100 series steels through the addition of cobalt as an alloying element.

Unimach UCX2 has proved highly reliable for the production of full-sized rocket motor cases at yield strength levels of 225,000 to 235,000 psi. When properly tempered to above strength levels, the new alloy is said to show essentially no notch sensitivity. The steel also has good forming characteristics and weldability.

Complete sponge iron plant

A sponge iron plant with a 500-ton daily rated capacity is being completed at Monterrey, Mexico, and will soon begin operation. The plant, on a site adjoining the original 300-tpd HyL sponge iron plant, will be operated by Fierro Esponja, a subsidiary of Hojalata y Lamina. Most of the output is expected to be used by Hojalata y Lamina to increase the percentage of sponge iron in its electric furnace charge. Description of the original HyL plant was given on pp. 315 to 318 of the May 1959 issue of JOURNAL OF METALS.

Develop hot cracking test

A simple, inexpensive test for predicting hot cracking in stainless steels and other alloys has been devised by a Westinghouse Electric Corp. reseacher. Until Dr. T. C. Hull's discovery, the only satisfactory test had been to prepare large samples representative of the final structure, and then actually to test-weld them.

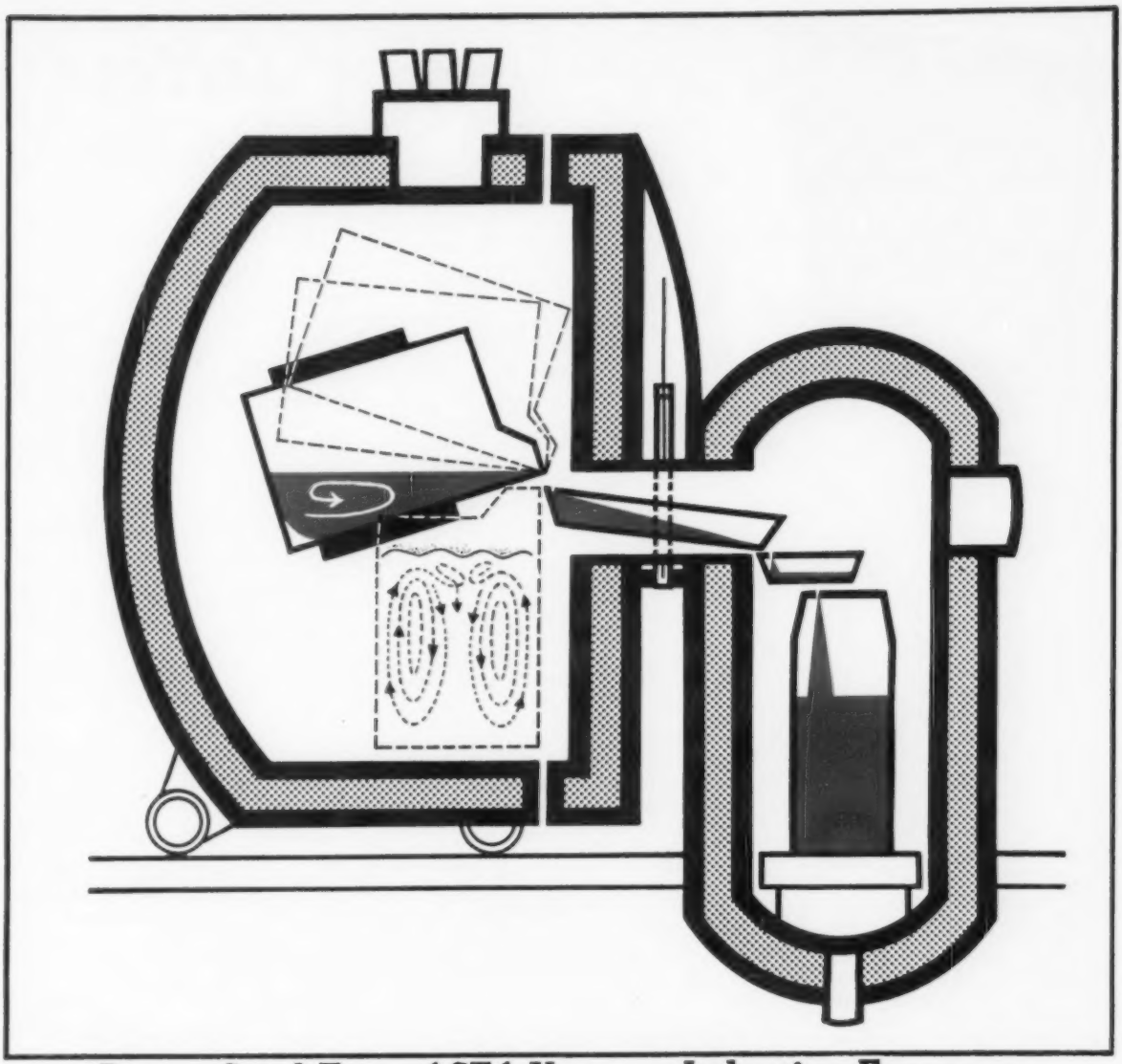
Dr. Hull's test is based on the fact that the tearing of a metal casting as it cools and shrinks from a liquid into a solid is comparable to the cracking of a weld as it freezes. Therefore, the study of small casting for hot cracking susceptibility is equivalent to the study of welds in very large samples of the metal. To do this, Dr. Hull uses a process called levitation melting. A 20-g sample can be prepared in a matter of 10 to 15 sec in a protective argon atmosphere.

"After the sample is melted," the researcher explains, "the molten metal pours into a copper mold of special design. The metal freezes into the shape of a tapered pin that averages about 2 in. in length and ¼ in. in diam.

"The top and bottom of the pin lock in place to prevent normal contraction of the metal," Dr. Hull continues. "Therefore, tensile stresses are set up in the pin as it cools and shrinks inside the mold. These stresses tend to cause the metal to tear apart. The longer and slimmer the pin, the greater the tearing. By comparing pins of different lengths and diameters, a scale is built up to describe the susceptibility to hot cracking numerically. The scale is then used for evaluating this characteristic in alloys of different compositions."

An error . . . an apology

On the Reporter pages of the February issue under the heading: *USBM reports 1959 outputs*, we mentioned new aluminum production facilities brought into operation during the year. One sentence read: "Early in 1959, Oregon Metallurgical Corp. began operating its fifth and last line in Ohio." It should have read, "Early in 1959 Ormet began operating its fifth and last line in Ohio." Our apologies to all concerned!—Ed.



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BOOKS

(Continued from page 182)

Stampings, by Federico Strasser, *Chilton Co.*, 175 pp., $10, 1959—Certain fundamental ideas about mechanical design are presupposed for the study of this text, although a specialized education is not a requisite. It is intended for anyone engaged in or interested in the production of articles made of die-produced components. Included are 555 illustrations. •

Foundry Engineering, by H. F. Taylor, M. C. Flemings, and J. Wulff, *John Wiley & Sons, Inc.*, 407 pp., $9.75, 1959—The authors, all AIME members from the Massachusetts Institute of Technology, have designed this book as an introductory text to metal casting. Up-to-date coverage is included on such topics as refractories, casting processes, melting equipment and practices, sand reclamation and control, welding, and heat treatment. •

Methods of Experimental Physics, Vol. 6, Pt. A: Solid State Physics: Preparation, Structure, Mechanical, and Thermal Properties, by K. Lark-Harowitz and V. A. Johnson, *Academic Press*, 466 pp., $11.80, 1959—Essentially six parts make up these facets of solid state. Following an introduction to the subject comes a section on preparation and purification of materials. Then follow discussions of crystal structures determination, mechanical properties, thermal properties, and solid state studies under high pressure. Among the contributors are AIME members Marvin Metzger, J. F. Radavich, T. A. Read, Morris Tanenbaum, and C. A. Wert. •

Methods of Experimental Physics, Vol. 6, Pt. B: Solid State Physics: Electrical, Magnetic, and Optical Properties, edited by K. Lark-Harowitz and V. A. Johnson, *Academic Press*, 416 pp., $11, 1959—In the beginning of this series, as in this present latest volume, the editors strive for a "concise, well-illustrated presentation of the most important methods, or general principles needed by the experimenter, complete with basic references for further reading." They give limitations of both applicability and accuracy, while discussing the interpretation of experiments, the evaluation of errors, and the validity of approximations. The book is designed to guide both the graduate student and the advanced research worker on experimental research of which they already know the basic principles.

Electrical properties . . . galvanomagnetic and thermomagnetic effetcs . . . magnetic properties . . . optical properties . . . luminescence . . . are photoelectric phenomena are the volume's topic headings. Among the contributors is AIME member J. J. Becker. •

Zinc—The Science and Technology of the Metal, Its Alloys and Compounds, edited by C. H. Mathewson, *Reinhold Publishing Corp.*, 721 pp., $19.50, 1959—Appearance of this volume fulfills the advance notice given in the Feb. 1959 issue, p. 99. The editor is C. H. Mathewson, after whom the Institute of Metals Division's Annual Award is named. Contributors to the book are also men of eminence in the field, with an overwhelming percentage, members of The Metallurgical Society, AIME. Represented are E. A. Anderson, H. D. Carus, G. F. Halfacre, W. T. Isbell, T. D. Jones, J. L. Kimberley, R. J. Lapee, H. E. Lee, C. H. Mathewson, C. W. Morrison, K. A. Phillips, J. P. Rankin. H. W. Schadler, R. Schuhmann, Jr., A. P. Thompson, Sam Tour, G. H. Turner, F. S. Weimer, T. H. Weldon, and G. T. Wever.

A discussion of the book's contents will be found in the previously mentioned February article. •

Aluminum Construction Manual, *The Aluminum Association*, 392 pp., $3, 1959—A reference work for use in aluminum structuring, this volume is divided into five parts. The first section gives available aluminum structural shapes, their dimensions, weights, and properties. Part two covers detailing practice and riveted and bolted connections. Emphasis on alloy 6061-T6 is given in part three, while part four deals with nine of the basic aluminum structural alloys. Section five is a compilation of tabular matter used in deriving specifications. •

letters

to the editor

Errata

By and large I think you do a swell job of editing the JOURNAL OF METALS, but I have to register a complaint when you goof on the facts to our disadvantage. On page 57 of the January issue, the article on John Price Hirth's receiving the Hardy Gold Medal, you have stated that he received his Ph.D. from M. I. T. He received his Ph.D. at Carnegie Tech!!

W. O. Philbrook
Professor of Metallurgy
Carnegie Institute of Tech.

Somehow the affiliation got garbled. In the same article the name of Norbert F. Neumann was inadvertently omitted as a former winner of the Hardy Medal. Our apologies to all concerned.—Ed.

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editorial

Research, Key to a Better Future

With respect to research, the role of The Metallurgical Society, as well as other technical societies, is twofold: first, to encourage research and, secondly, to act as a clearing house, making results of such research available to scientists, engineers, and industries.

An example of important research now underway is the basic research on the chemical and physical properties of ores, concentrates, reducing agents, and other furnace charging materials. The metallurgical importance of this field of research is so great that an International Symposium on Agglomeration is now being readied and will take place in Philadelphia in April 1961. This symposium is being organized under the sponsorship of The Metallurgical Society and the Society of Mining Engineers.

In another area, research, especially post-war research, by iron and steel metallurgists is now beginning to make itself felt by the emergence of *short cut* steelmaking processes adopted for economic competition in specific situations. Even in large steel works, research on short-cut processing is paying dividends, and many companies are increasing their steelmaking capacity without installation of additional furnaces. The Iron and Steel Division of The Metallurgical Society has recognized the growing importance of these new processes by organizing a Basic Oxygen Steel Committee.

Extractive metallurgists are carrying out research leading toward increasingly important applications of such chemical engineering processes as solvent extraction, autoclave oxidation and reduction, dialysis, and ion exchange. The sudden demand for exotic metals, such as uranium and metals of the rare-earth group, gave great emphasis to metallurgical research in these techniques.

An increasingly important development in metallurgical research is the sponsorship of both basic and applied research by trade associations of the metals industries. During the last half of the *fifties* at least two groups of nonferrous metals industries have established cooperative programs for research, both basic and applied, in the technology of products application.

Research in physical metallurgy and on the properties of materials outweighs in sheer volume all other categories of metallurgical research. Not only are there more physical metallurgists engaged in research than any other branch of metallurgy, but physical metallurgists have gone further in discovering and defining the basic scientific principles determining the properties of metals. So successfully has research developed the science of metallurgy that the basic concepts are now being extended beyond metals, strictly speaking, and are being applied broadly to materials.

With this success in basic science, metallurgical engineers are coming to realize the great advantage derived by considering their profession to be concerned with the study and useful application of materials, rather than of metals only. Practical results of this thinking are furnished by such activities as the formation of the Metallurgy-Ceramics Foundation sponsored jointly by the American Ceramic Society, The Metallurgical Society of AIME, the American Society for Metals, and the National Science Teachers Association.

The concept of materials engineering as an outgrowth of metallurgical engineering is the source of considerable ferment in academic institutions. The American Society for Engineering Education, together with The Metallurgical Society and other professional and technical organizations, has sponsored and will continue to sponsor colloquia on the concept of viewing materials engineering as an outgrowth of metallurgical engineering research.

Thus, research is not only a key to a better future for the metallurgical industry, but it is also the key which promises growth and expansion of the metallurgical profession itself.

Carleton C. Long, President
The Metallurgical Society

Authoritative books for engineers

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Explains and illustrates applications, advantages, limitations of 24 different test methods applicable in every branch of engineering and industry. Specifications, equipment costs, hundreds of pages of test interpretation data. *Prepared under the auspices of the Society for Nondestructive Testing. 1,100 illustrations, graphs, tables; 1,910 pp. 106 Contributing, Consulting Editors. Robert C. McMaster, Ed. October, 1959.* 2 volumes, $24

PRODUCTION HANDBOOK

Packed with practical production know-how, this Handbook is the complete key to management-engineering methods that are revolutionizing industrial production today. Fully covers new materials, machines, processes, and proper functioning of company organization.

Supplies proved principles, time- and work-saving systems, and successful operating procedures for maximum productivity at minimum cost. Saves hours of research and costly experimentation. *726 illustrations, tables; 1,726 pp. 48 Contributing, Consulting Editors. Gordon B. Carson, Ed. 2nd Ed., 1958.* $16

MATERIALS HANDLING HANDBOOK

The complete guide to modern materials handling. This unique Handbook explains the governing principles, today's most efficient methods and systems, and recommended equipment for moving material at least cost — whether in raw, in-process, or finished form.

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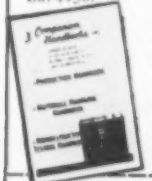

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personals

Lawrence M. Van Vlack, professor of materials engineering, University of Michigan, has been granted sabbatical leave for the first semester of 1960-1961 in order to study in the fields of solid state properties of ceramic materials and high-temperature ceramic/metal reactions. During the second semester of that academic year **Richard A. Flinn,** prof. of metallurgical engineering, will be on leave while revising two texts: **The Development, Selection and Control of Metallic Materials** and **The Fundamentals of Metal Casting.**

C. Arthur Zeldin is now supt. of operations at the Garfield refinery of Kennecott Copper Corp. With the company for the past 11 years, Mr. Zeldin has been engaged in the development of methods and plant design for continuous casting of copper. In his new position, he will be responsible for electrolytic copper refining, casting, precious metals, and byproducts recovery.

John D. Sullivan, technical director at Battelle Memorial Institute and member of The Metallurgical Society's Board of Directors, will receive The Albert Victor Bleininger Award for 1960 from The American Ceramic Society. The award, "the highest honor conferred in this country for distinguished achievement in the field of ceramics," is granted annually by the Society's Pittsburgh section. Presentation will be made on Mar. 11th.

Melvin C. Chang has been appointed supervisor of Chemical engineering and mineral processing at Crucible Steel Co.'s Central Research Laboratory. Dr. Chang was formerly research chemical engineer with Crucible Steel.

Donald F. Ingvoldstad is now assistant smelter superintendent at the Bunker Hill Co. With Bunker Hill since 1936, he was a research metallurgist until 1954, and more recently held the position of smelter chief research metallurgist.

Walter R. Hibbard, Jr., recently named to the post of Manager of the Metallurgy and Ceramics Research dept., General Electric Corp., and 1960 Vice President of the AIME, addressed the joint meeting of the Scientific Manpower Conference and American Association for the Advancement of Science in December.

Dr. Hibbard called for changes in graduate training for metallurgists in order to provide the teachers, facilities, and creative environment necessary to attract the most promising students. One such recommendation is time for "*creative idleness*—i.e., doing things which require the student's hands, but not his mind—such as polishing metal specimens. This situation produces a mental activity in which the mind wanders and seeks out subjects of primary interest, analyzes and synthesizes, develops new thoughts, and creates new approaches and ideas."

Gurdon M. Butler, Jr., has been named director of research for Gladding, McBean & Co., Los Angeles. Dr. Butler was formerly manager of engineering research for the Carborundum Co., Niagara Falls, N. Y.

John P. Denny has joined the technical division of The Beryllium Corp. as project supervisor in physical metallurgy. There he will be responsible for physical metallurgy activities in beryllium development. He was formerly a specialist in physical metallurgy with the General Engineering Laboratories of the General Electric Co.

Eric R. Jette has been appointed staff consultant to research administration, Union Carbide Corp. Since joining Union Carbide in 1956, Dr. Jette has been director of research for the Union Carbide Research Institute.

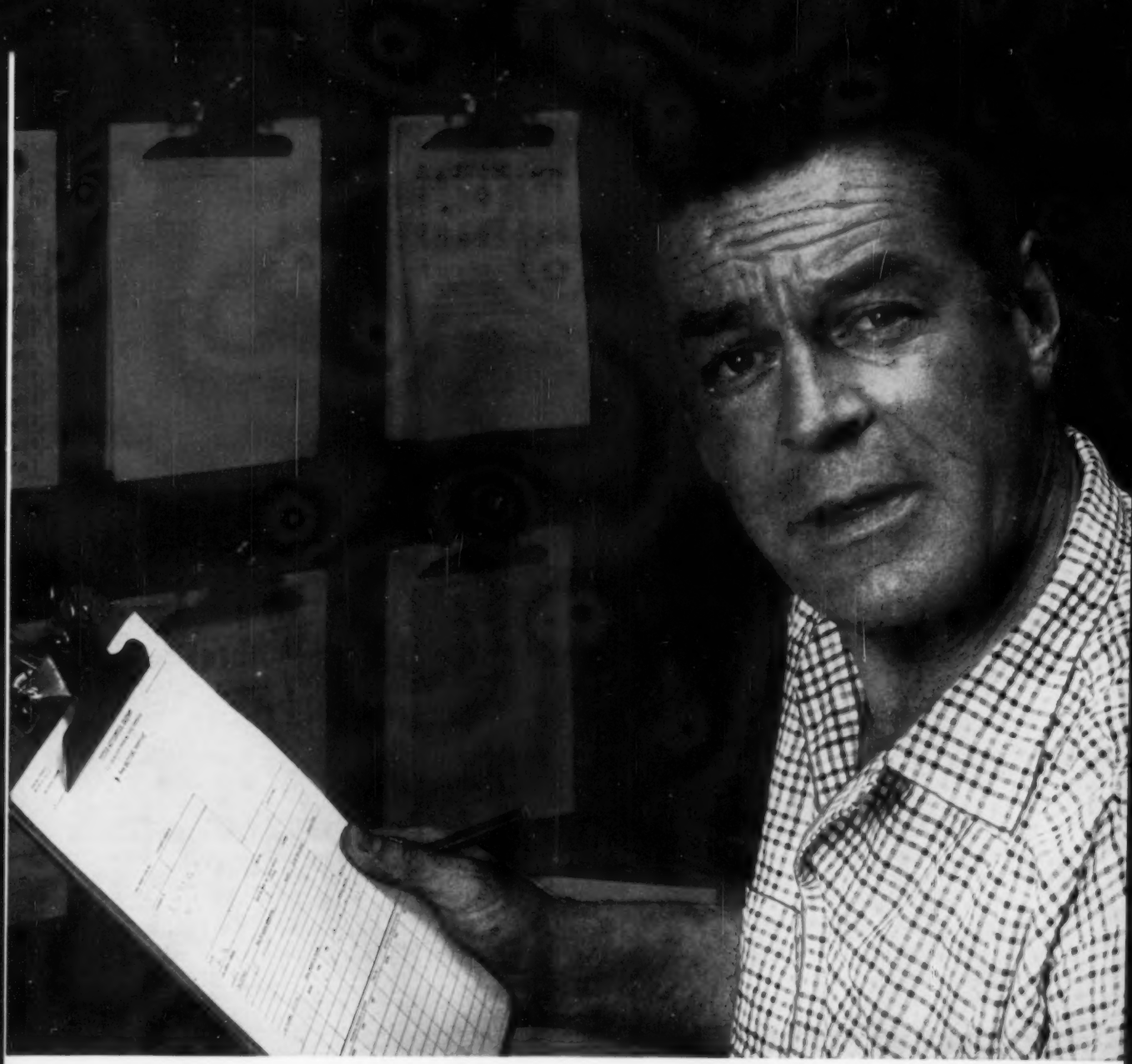
Dorace Dodd has been appointed assistant manager of the Tractor division's southern district, The Eimco Corp. He will continue to maintain his headquarters in Birmingham, Ala., where he had been senior sales engineer.

Franklyn J. Millhouse is now Pacific Coast sales manager for Great Lakes Carbon Corp.'s electrode div. Moving from Detroit, where he was the division's sales representative, he will take up residence in the San Francisco area.

A. B. Kinzel has been elected chairman of the Division of Engineering and Industrial Research of the National Academy of Sciences-National Research Council. His election to a two-year term is expected to put the engineering profession in a better position to assist in the determination of the National Academy of Sciences' policies.

Samuel L. Hoyt is in Europe as a special representative for the US Dept. of Defense's Research & Engineering div. In his year's mission he will be dealing with fundamental and applied research in NATO countries on materials in general and metallurgy in particular.

(Continued on page 241)



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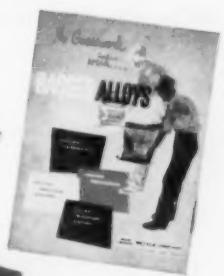

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TRANSACTIONS PAPERS ACCEPTED TO FEBRUARY 1, 1960

Preparation and Properties of High Purity Scandium Metal, by F. H. Spedding, A. H. Daane, G. Wakefield, and D. H. Dennison (EMD-IMD)

Use of Axis Distribution Charts to Represent Sheet Textures, by C. J. McHargue and L. K. Jetter (IMD)

Room Temperature Recovery of Internal Friction and Elastic Constants in Freshly Quenched Steels, by C. E. Beaulieu, A. Dubé, and G. Letendre (IMD)

Diffusion in the Solid Silver-Molten Lead System, by Roger E. Hudrlik and George W. Preckshot (EMD)

Phase Transformations in Nickel-Rich Nickel-Titanium-Aluminum Alloys, by R. F. Decker and J. R. Mihalisin (IMD)

Single Crystal Growth and Purification of Tantalum, by D. P. Seraphim, J. I. Budnick, and W. B. Ittner, III (IMD-EMD)

Kinetics of Hydrogen Reduction of Magnetite, by Jean M. Quets, John R. Lewis, and Milton E. Wadsworth (ISD)

A Study of the $\{10\bar{1}1\}$ and $\{10\bar{1}3\}$ Twinning Modes in Magnesium, by Robert E. Reed-Hill (IMD)

Dislocations in Deformed Single Crystals of α-Brass, Part I—General Observations, by J. D. Meakin, H. G. F. Wilsdorf (IMD)

A Liquid Phase Coating for Molybdenum, by G. D. Oxx, Jr. and L. F. Coffin, Jr. (IMD)

Co-Rich Intermediate Phases in the Cb-Co System, by Shozo Saito and Paul A. Beck (IMD)

Effect of Si and Al on the Stability of Certain Sigma Phases, by K. P. Gupta, N. S. Rajan, and Paul A. Beck (IMD)

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Self-Diffusion in Gamma Uranium, by S. J. Rothman, L. T. Lloyd, and A. L. Harkness (IMD)

A Mutual Solid Solubility Scale for Metals, by Y. L. Yao (IMD)

Effect of Heat Treatment in the Ferrite-Austenite Region on Notch Toughness of Low-Carbon Steels, by W. C. Leslie, R. L. Rickett, and W. D. Lafferty (IMD)

Quantitative Addition and Recovery of Oxygen Isotopes in Niobium (Columbium), by W. F. Harris, W. M. Hicham, M. H. Loeffler, and D. H. Shaffer (IMD)

The Isothermal Transformation of Eutectoid Beryllium Bronze at High Temperatures, by Jack S. Brett, George L. Kehl, and Emilio Jaraiz-Franco (IMD)

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The importance of Iron and Steel Division activities is reflected in the active support of these activities by men in all phases of the ferrous metals field. A number of ISD meetings have become nationally famous.

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CONDENSED PROGRAM

Sponsored by the Blast Furnace, Coke Oven, and Raw Materials Committee and the National Open Hearth Steel Committee of the Iron and Steel Division of The Metallurgical Society of AIME

Palmer House, Chicago — April 4-6, 1960

CONDENSED BLAST FURNACE PROGRAM

Sunday, April 3

3-9 pm **Registration**

Monday, April 4

8 am-5 pm **Registration**

9:30 am **Blast Furnace Practice Session**

Technology of carbonaceous blast furnace tap hole and through mixes; design, construction, and operating features of a new merchant blast furnace plant automatic stockhouse programming; nuclear stockline gage for blast furnaces.

9:30 am **Coal Session**

Use of coal plasticity in coke plant coal blending; fine coal cleaning with the circular concentrator table; nature of coking coals and the mechanism of coke formation; technical and economic effects of moisture in coking coals.

9:30 am **Iron Ore Reduction Session**

The Alan Wood H-iron plant; thermodynamics of direct reduction processes; kinetics of hydrogen reduction of hematite; study of the kinetics of magnetic roasting; direct reduction of fine iron concentrates in a self-agglomerating fluidized bed.

2:00 pm **Blast Furnace Theory Session**

Predicting blast furnace performance from operating and thermal data; injection of different materials in the blast; investigations on the enrichment of blast furnace air; results of research carried out in 1959 at the International low-shaft blast furnace—fuel oil and gas injection.

2:00 pm **Coke Session**

Recent developments in British coal carbonization research; coking pressure and its measurement—current theory and practice; progress report on computer simulation of heat transfer in coke ovens; repair of oven floors in coke battery No. 1 of the Brazilian National Steel Company, Volta Redonda, Brazil.

Tuesday, April 5

9:30 am **Sintering Session**

Use of preheated air in sintering; sinter plant controls; calcium ferrites in relation to the sintering of iron ores; a dilatometer investigation into the sintering of iron ores; sintering characteristics of Wabush specular hematite.

9:30 am **Coal Chemicals Session**

Coal chemical recovery and processing operations at the Youngstown plant of Republic Steel Corporation; optimum operation in the recovery of light oil; coke oven gas separation by means of low temperatures; operation of a light oil extraction dephenolizing plant with contact towers; recovery of anhydrous ammonia from coke oven gas.

9:30 am **Computer Simulation Session**

An analysis of blast furnace stove performance using special temperature measurements; direct analog computer for thermal problems in blast furnaces and coke ovens; computer study of the kinetics of reduction of iron ore in a fluidized bed.

2:00 pm **Joint Session**

Development of the Zonguldak coal field in Turkey; high-temperature evaluation of blast furnace coke; hot-blast water-cooled cupola as applied to steelmaking.

6:30 pm **Reception**

7:00 pm **Annual Fellowship Dinner**

Wednesday, April 6

8 am-4 pm **Registration**

Plant trips, see next page.

CONDENSED OPEN HEARTH PROGRAM

Sunday, April 3

3-9 pm **Registration**

Monday, April 4

8 am-5 pm **Registration**

9:30 am **General Session**
Welcoming remarks; announcements and reports; McKune Award paper.

10:30 am **Basic Operations Session**
Steel production with safety.

10:30 am **Acid Operations Session**
Practical method for statistical evaluation of open hearth problems; use of ultrasonics in testing for steel cleanliness; open discussion on new bottoms —maintenance and repair.

2:00 pm **Operating Metallurgy**
Computer study of open hearth operation with oxygen roof lances; a general method for the analysis of plant operating data using a digital computer tied to a study of an open hearth furnace using a roof lance; metallurgical aspects of oxygen roof lancing; vacuum-flow degassing of open hearth steel.

2:00 pm **Open Hearth Refractories**
(To Be Announced)

Tuesday, April 5

9:30 am **Basic Oxygen Furnace Operating Session**
Experience and technical problems in making high, medium, and low-carbon steels; basic problems encountered in handling materials and products; basic oxygen furnace with cupola iron.

9:30 am **Operating and Combustion Session**
Production advantages from the use of oxygen roof lances; refractory problems resulting from the use of oxygen roof lances; design problems—oxygen roof lances; fuel and firing practices with oxygen roof lances.

2:00 pm **Basic Oxygen Furnace Refractories**
Furnace linings; ladle refractories.

6:30 pm **Reception**

7:00 pm **Annual Fellowship Dinner**

Wednesday, April 6

8 am-4 pm **Registration**
Plant trips, see above.

Important

All operating men, repair and maintenance men, metallurgists, ceramic and refractory engineers, observers, and any others interested in the production of more steel, better steel, and cheaper steel and in any of the problems connected with the reduction of iron ore in the blast furnace are invited to attend. The complete program will be mailed this month, but make plans now to attend this important Conference.

The registration fee for either Conference is ten dollars ($10.00), which includes a copy of the respective Proceedings when printed. There is no registration fee for students at any of the sessions, unless they desire a copy of the Proceedings. AIME members are entitled to a three dollar ($3.00) reduction in the registration fee upon presentation of their membership card.

The two meetings promise to be extremely valuable; by registering for both, it is possible to receive both volumes of Proceedings.

Hotel Reservations

Adequate hotel facilities will be provided at the Palmer House and other Chicago hotels. Hotels, however, will not hold blocks of rooms assigned to this meeting after March 21. Single rooms are limited. Hotel reservation requests should, therefore, be sent directly to the hotel of your choice as soon as possible. Be sure to mention the Blast Furnace or Open Hearth Conference of AIME as well as the time of arrival in making your request.

Plant Trips

Through the courtesy of Acme Steel Company and Inland Steel Company, inspection trips have been arranged through their plants on Wednesday, April 6.

Buses will depart from the Palmer House at 9:00 a.m. Visitors to Acme Steel Company will see the new oxygen steelmaking facilities and hot blast cupolas. At Inland Steel Company, the blast furnaces and new sintering plant will be visited. A charge of $3.00 will be made by the National Open Hearth Steel Committee and the Blast Furnace, Coke Oven, and Raw Materials Committee to help defray the expense of plant trips, transportation costs, and other non-technical conference expenses. (Use of private cars will not be permitted at the plants. Please cooperate by planning to use the special buses.)

Nonmembers welcome!

Of course nonmembers are welcome at the Open Hearth and Blast Furnace Conferences, just as they are at all activities sponsored by The Metallurgical Society through its Divisions and Technical Committees. However, they are also reminded that such activities are available only because the majority of those who take advantage of them acknowledge their professional obligation by supporting their professional society.

Conference membership committees will be active throughout the Conferences, greeting nonmember guests and inviting them to consider membership in AIME. If you are a member, make it a point to invite the first nonmember you see to make your Society his Society as well—you'll both benefit. If you're not a member, stop by the Membership Desk and see what you're missing!

ANNUAL REPORT of The Metallurgical Society

by R. W. Shearman, Secretary of The Metallurgical Society
(Abstract from the complete report)

The year 1959 will be recognized as one of increased growth of The Metallurgical Society in many directions—more scientific literature published, more income to the Society, and, inevitably, more expenses.

Plans for membership growth have begun to materialize with a net increase of 468 members in 1959, giving a total of 7,765 corporate members. In addition, student membership totals 612.

Service to members is most clearly recognized in the two media of programming and publications. In both of these areas The Metallurgical Society has expanded its services. During 1959, nine major technical meetings were held at the national level, attracting an audience of approximately 6200 and presenting a total of over 600 technical papers. Pages published in all media totaled over 5700—an increase of 70 pct over 1958.

To meet the need for Conference Proceedings, The Metallurgical Society concluded an agreement with Interscience Publishers, Inc., to handle the series of **Metallurgical Society Conferences.** In 1959, the first four volumes came off the press. Three more are *in the works*, and six volumes will result from 1960 Conferences and Symposia.

Staff Changes

In November, the Assistant Secretary of The Metallurgical Society, D. C. Johnston, took on the additional assignment of Secretary-Treasurer of the Institute of Metals Division, replacing R. W. Shearman in the post. Because of expansion of his work, a full-time secretary was hired during the year to assist Mr. Johnston.

The Managing Editor of JOURNAL OF METALS was given the title of Editor-in-Chief in November, filling the position nominally held by R. A. Beals as Editorial Director of the magazine.

Following the resignation of J. B. Van Cronkhite as News Editor of JOURNAL OF METALS, this position has been filled by R. M. Schelkopf.

Total staff of The Metallurgical Society in New York is now eleven, five of whom are responsible for publication of JOURAL OF METALS. In addition, the Editor of TRANSACTIONS of The Metallurgical Society of AIME, Professor Gerhard Derge, is located at Carnegie Institute of Technology. He has the help of an Editorial Assistant.

Transactions

The year 1959 marked the first full year that TRANSACTIONS OF THE METALLURGICAL SOCIETY OF AIME was published by the photo offset process. During the year, 1064 pages of technical articles were published. The following is a breakdown of papers published by the three divisions of The Metallurgical Society in 1959 and 1958:

Division	No. of Papers and Notes 1959	1958	Pages 1959	1958
Extractive Metallurgy	20	21	89.0	107.0
Institute of Metals	186	169	873.0	695.0
Iron and Steel	14	15	102.0	82.5
	220	205	1064.0	886.0

The budget for 1960 is based on the printing of 1152 pages in six issues of 192 pages each.

The format of the TRANSACTIONS remained substantially the same during 1959, with the exception that Technical Notes have been moved to the back of each issue, instead of being scattered in random fashion throughout the magazine.

Income from reprints has proved to be a recognized source of revenue for support of the publication of TRANSACTIONS. Certain changes in procedures will be made in 1960 so that authors will receive both their complimentary and purchased reprints soon after publication. The yearly index has been included in the back of the December 1959 issue for the first time in recent years. It is believed that this added service to readers of the TRANSACTIONS should prove of value. Plans have been completed to solicit a limited amount of advertising on the covers of the bimonthly TRANSACTIONS during 1960.

Attention is called to the increase in subscriptions to TRANSACTIONS, $24,710 in 1959 as compared to $20,363 in 1958.

During 1959, Volume 212 (The Metallurgical Society) of AIME TRANSACTIONS was published, and was available over a month earlier than previous volumes. Volume 215, containing 1959 papers, should be ready still earlier, due to inclusion of the index in the December issue.

The importance of TRANSACTIONS in its field was indicated in a survey of metallurgical literature reported in *American Documentation*. This statement was made: "The AIME TRANSACTIONS is clearly the predominant journal in the field, receiving more than twice as many citations as the title ranking second. Five other titles, all cited more than 100 times, are especially important: *Acta Metallurgica*, *ASM Transactions*, *Journal of Applied Physics*, *Physical Review*, and the *Institute of Metals Journal*, the highest ranking foreign title. It is of interest to note that there were sufficient non-TRANSACTIONS articles cited to give the JOURNAL OF METALS 10th place."

JOURNAL OF METALS

As the monthly periodical of The Metallurgical Society, JOURNAL OF METALS has endeavored to carry out its mandate of producing a vital, more readable magazine for the metallurgical profession. By means of short, concise articles, the JOURNAL has attempted to keep its readers better informed on worldwide metallurgical developments.

The latest feature added to the JOURNAL is Phases and Processes. This monthly column is designed to keep its readers up-to-date on all important areas of metallurgy.

A salary survey of the metallurgical profession was presented in 1959 for the first time.

The Reporter page has been radically changed in typography. By enlargement to two pages, the month's metallurgical news can be more adequately covered.

On alternate months, the JOURNAL OF METALS carries the contents of that month's issue of TRANSACTIONS and on other months the listing of papers accepted for TRANSACTIONS.

During 1959, a total of 860 pages was published by JOURNAL OF METALS, compared to 824 pages in 1958. The breakdown between editorial and advertising is given below:

	1959	1958
Pages of editorial material	578	566
Pages of advertising:	282	258
	860	824

Subscriptions to JOURNAL OF METALS have continued to increase, and the number of copies of each issue printed (other than special issues) increased from 10,300 at the beginning of the year to 11,200 at year's end.

Publication Arrangement

The Metallurgical Society concluded a three-year agreement with Interscience Publishers, Inc., to publish a new series of books entitled *Metallurgical Society Conferences*. Each volume of the series will be the proceedings of a technical conference sponsored by the Society or one of its technical committees. Uniform in format, the books will afford the rapid and coordinated publication of scientific and technical information.

Under terms of the agreement, proceedings volumes are made available to conference registrants at approximately cost price. Proceedings are sold to members not attending the conference at a considerable discount. For copies sold to non-members, the publishers will return a royalty to the Society.

Meetings

In addition to traditional conferences, The Metallurgical Society and its technical committees sponsored three major conferences of national and international importance. These were:

1. Conference on Physical Metallurgy of Stress Corrosion Fracture.
2. International Symposium on the Physical Chemistry of Process Metallurgy.
3. Conference on Properties of Elemental and Compound Semiconductors.

It is interesting to note that The Metallurgical Society and its technical committees presented a total of 638 papers at 122 technical sessions before an audience totalling approximately 6200. Not included in these statistics are the many technical meetings of local sections of AIME, local sections of the National Open Hearth Steel Committee, and these two major regional meetings:

1. Pacific Northwest Regional Conference, Olympic Hotel, Seattle, Wash., April 16-18, 1959.
2. New England Regional Conference, Statler Hotel, Hartford, Conn., May 21-22, 1959.

Division and Committee Activities

The Iron and Steel Division is now actively studying the scope of its present technical committees in order to assure that new processes, such as oxygen steelmaking and direct reduction of iron ore, are covered in the most efficient fashion. An *ad hoc* Scope Committee is preparing a report.

The Extractive Metallurgy Division has appointed an *ad hoc* committee to study the long-term objectives of the Division. The committee's charter includes the study of better programming of technical subjects at Annual Meetings and Regional Meetings, and the publication of technical literature.

The Institute of Metals Division is continuing the study of *scope*, and is concerned with adequate coverage by technical committees of newer metals such as zirconium and hafnium. Introduction of papers on Research Management is under consideration. A Forum on Metallurgy in the Navy was presented at the 1960 Annual Meeting, to be followed by a program on the Army at the 1960 Fall Meeting, and on the Air Force at the 1961 Annual Meeting.

Supervision of the New England Regional Conferences has been transferred from the Institute of Metals Division's Executive Committee to the Board of Directors of The Metallurgical Society.

Membership

Membership statistics for The Metallurgical Society in 1959 are given in the following tabulation:

	Gain	Loss	Net	Total Membership as of December 31, 1959
ISD	348	168	180	2,669
EMD	98	76	22	1,207
IMD	320	210	110	2,694
Council of Education	20	2	18	40
Council of Economics	16	8	8	66
Unclassified	201	71	130	1,089
Total	1003	535	468	7,765
Student Members				612
Total Corporate and Student Members				8,377

Compared with 1958, this year has been considerably more successful with respect to membership growth. The net gain of corporate members is more than double as a result of increased gains and reduced losses. The higher gains reflect an increasing effort to analyze and utilize numerous sources of new members, among which the most important is non-member participation in Society-sponsored activities; the reduced losses may be attributed in large part to the improved economic picture in 1959.

A basic aim of the membership campaign now underway is to make it impossible for a non-member to participate in a Society activity without being asked to become a member. At the same time, members participating in the same activities are reminded of the importance of continued growth and urged to assist in the drive for new members. This approach has resulted in distribution of over 5000 application forms during 1959. Follow-up of nonmember prospects has been maintained by mail using personalized invitation letters and descriptive brochures, including a new booklet entitled *The Metals Man and His Society* produced in the fall for this purpose.

This year marked the start of organized effort by the Society in connection with increased student membership among metallurgical students in schools having AIME Student Chapters. Working jointly with the Society of Mining Engineers, a facsimile insurance policy entitled *A Policy for Career Security* was produced and distributed through faculty sponsors to non-member students in these schools. Over 6000 copies were distributed in October, with over 40 pct going to metallurgy students. Since about 25 AIME Student Chapters currently serve potential members of The Metallurgical Society, the balance of this activity has been directed to these groups. Portfolios containing various material for use by the Chapters were distributed in October and a Student News page was established in JOURNAL OF METALS beginning with the January issue. Finally, the Assistant Secretary has been able to visit almost one-half of the chapters, meeting and discussing chapter operations with both student officers and faculty sponsors.

Acknowledgment

Recognition is gratefully accorded the many members of AIME who served as officers or committee members during the year, and those who planned technical programs and edited the technical papers for the proceedings. Without their loyal help and their devotion to AIME, The Metallurgical Society could have recorded no progress.

Gratitude is due the industrial organizations that have continued their financial support to the Metals Research Publications Fund. Without their understanding assistance, publication of important research and engineering papers would have been sharply curtailed.

Respectfully submitted,

R. W. Shearman, Secretary
The Metallurgical Society

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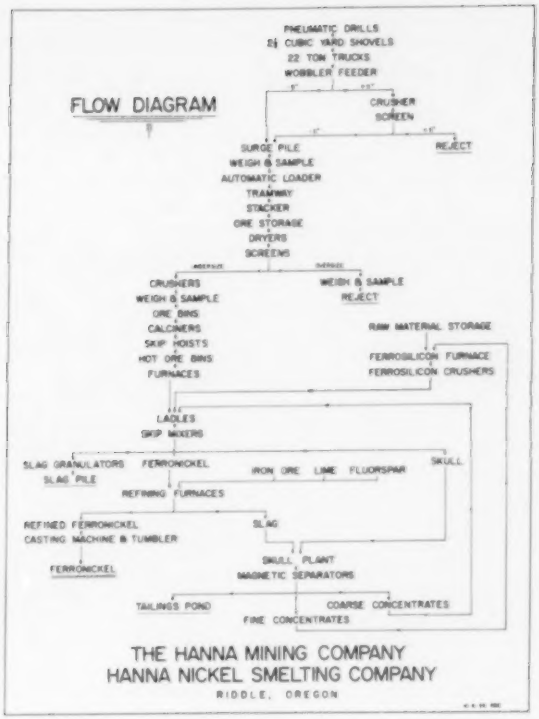
FERRO-NICKEL PRODUCTION IN OREGON



A description of the only major nickel smelting operation in the US . . . Hanna's plant for the production of ferro-nickel from low-grade lateritic ores near Riddle, Ore.

E. E. Coleman and D. N. Vedensky

NICKEL Mountain, some 4 miles from Riddle, Ore., is the site of open-pit mining and smelting activities of Hanna Nickel Smelting Co., a wholly-owned subsidiary of Hanna Mining Co. In this low-grade lateritic ore deposit, the nickel mineral is *garnierite*, a complex silicate of nickel ($H_2(Ni,Mg)SiO_4 + H_2O$) associated with iron, cobalt, chromium, and aluminum. The ore contains from 17 to 25 pct moisture; its average dry analysis is shown in Table I.

The ore body is ideally suited to open-cut mining methods, and practically no stripping is required since mineralization extends to the surface in most places. The ore is generally soft and can be mined without blasting. Output is in excess of 3000 tons of crude ore per shift.

Ore is moved by 22-ton trucks to a screening and crushing plant where +5-in. ore is crushed in a 30x42-in. jaw crusher. Crushed −3-in. ore, together with the −5-in. uncrushed ore, is conveyed by a 8306-ft tramway to the smelter stockpile, some 2000 ft below the mine.

E. E. COLEMAN and D. N. VEDENSKY are with the Hanna Nickel Smelting Co., Riddle, Ore., and the Hanna Mining Co., Cleveland, Ohio, respectively. This paper was delivered at the International Symposium on the Extractive Metallurgy of Copper, Nickel, and Cobalt during the 1960 AIME Annual Meeting.

The first step in processing ore is to reclaim it from the stockpile and then remove sufficient free moisture so that it can be screened and crushed. Ore is reclaimed from stockpile by a 2-cu yd electric stripping shovel or by a bulldozer. By cutting the stockpiled ore at right angles to the axis of the bedding planes, additional blending of the smelter feed is accomplished.

Two rotary dryers, 10 ft in diam and 100 ft long, are used to dry the ore. They are concurrently fired, the heat normally being supplied by burning *hogged fuel*, a waste wood product from local saw mills. Auxiliary oil burners are available for use, if the hogged fuel supply should become inadequate.

Hogged fuel is burned in two Dutch ovens, one for each dryer. Each oven consists of two fuel burning cells equipped with water-cooled cast-iron section grates, and one secondary combustion chamber. Hogged fuel is piled on the grates by large screw feeders, and combustion is maintained by undergrate forced draft. Each Dutch oven is rated at 82.5 million Btu per hr at 1900°F exit gas temperature. Hot gases are drawn through the dryers by 125-hp induced draft fans and discharge gas temperatures run from 175° to 240°F. From 18 to 24 tons of ore is dried per unit of hogged fuel consumed. (One unit equals 200 cu ft, and heat content is approximately 18 million Btu.)

After drying to 3 to 4 pct free moisture, the ore is transported by belt conveyor to the crushing and screening plant, where it is first passed over a double-deck screen, provided with 1¼-in. top and ⅜-in. bottom openings. The oversize, analyzing some 0.7 pct Ni and predominantly hard peridotite, is rejected. Normally, some 17 to 18 pct of the total weight of ore is thus discarded. Rejection of peridotite reduces the magnesia in the smelter feed, and the resultant product is, thus, enriched in nickel content. The resulting smelter feed has the approximate analysis shown in Table II.

All intermediate-size material from the primary screen is passed to either of two 4-ft cone crushers in closed circuit with a second screen, provided with 1-in. top and ⅜-in. bottom openings.

From the screening and crushing plant the ore first passes to a continuous sampling plant and then into silo storage bins of sufficient capacity to supply the smelter for two days.

Calcining

Ore can be drawn from any of the storage bins to feed the calciners, two 9-ft diam by 250-ft long variable-speed rotary kilns countercurrently fired by fuel oil. In the kilns, with a residence time of about 1½ hr, the ore is heated to 1200° to 1300°F. This removes the remaining free moisture, as well as 60 to 70 pct of the combined water. This operation is necessary to reduce the tendency of the ore to boil in the melting furnaces. Fuel consumption is approx 7.3 gal per ton of ore calcined, and kiln capacity is 45 to 50 tons of feed per hr per kiln.

Hot ore discharging from the kilns is transported by inclined automatic skip hoists to two distributing points above the roof of the smelter building. From these distributing points, the ore flows by gravity to four 50-ton capacity furnace feed bins directly above the melting furnaces. Every effort is made to conserve the heat of the ore. Skip loaders, skip cars, transfer pipes, and furnace feed bins are insulated. Generous use is made of stainless steel where hot ore must contact bare metal.

Ugine reduction process

The reduction of nickel and iron from ore is accomplished by the Ugine process, patented by René Perrin in France. This process involves the addition of a suitable reducing agent to a mixture of molten oxide ore in the presence of molten ferrous metal, using violent agitation for mixing the reducing agent and molten material. In this process, the exothermic heat of the reaction assists in maintaining a high temperature during the reduction cycle.

The Ugine process is particularly adaptable to lateritic-type, low-grade nickel ores of high magnesia content. It is especially attractive in an area where low-cost electric power makes electric furnace melting economic. In Hanna's adaption of the Ugine process, silicon is used as the reductant; it is added in the form of 45 pct Fe-Si. Agitation of the reductant and the molten ore is accomplished by pouring material rapidly from ladle to ladle.

According to the electromotive series, the sequence of oxides reduction involved is as follows: trivalent iron to divalent iron, nickel oxide to metallic nickel, and divalent iron to metallic iron. Thus, the first reaction is

$$2Fe_2O_3 + (Fe)Si \rightarrow 4FeO + SiO_2 + (Fe).$$

The iron content of the ferro-silicon, as indicated by the parentheses, goes directly to metal.

Next nickel oxide is reduced by the following reaction:

$$2NiO + (Fe)Si \rightarrow 2Ni + SiO_2 + (Fe).$$

The third step in the sequence reduces sufficient divalent iron oxide to control the grade of ferro-nickel and insure good reduction of nickel:

$$2FeO + (Fe)Si \rightarrow 2Fe + SiO_2 + (Fe).$$

As previously mentioned, the iron content of the ferro-silicon introduced into the reactions goes directly to ferro-nickel. This, in effect, dilutes the ferro-nickel and reduces the amount of iron that must be recovered from ore for any given grade of product. Therefore, there is a definite limit to the grade of nickel than can be reached in the final product for any given grade of ferro-silicon used. Any attempt to exceed this limit results in reduced nickel recovery. On the other hand, reducing an excessive amount of iron to produce a lower grade product requires excessive amounts of ferro-silicon. It has been found that the best over-all operating economies exist when producing ferro-nickel containing approximately 45 pct Ni.

Ferro-silicon is crushed to −⅝-in. It has been found that larger sizes do not melt with sufficient rapidity to provide intimate mixing. On the other hand, crushing to a smaller size results in the production of excessive amounts of fine material, which is carried away from the ladles by rising currents of hot gases.

The average consumption of 45-pct Fe-Si is 1.77 lb per lb of nickel contained in molten ore. Approximately 44.5 pct of this is required for reducing trivalent iron, 30 pct for reducing nickel, and 10.5 pct for reducing divalent iron. About 15 pct of the consumption is not accounted for by the above reactions. Mechanical loss of fines and oxidation of ferro-silicon during pouring are responsible for this loss.

Carbon reduction investigated

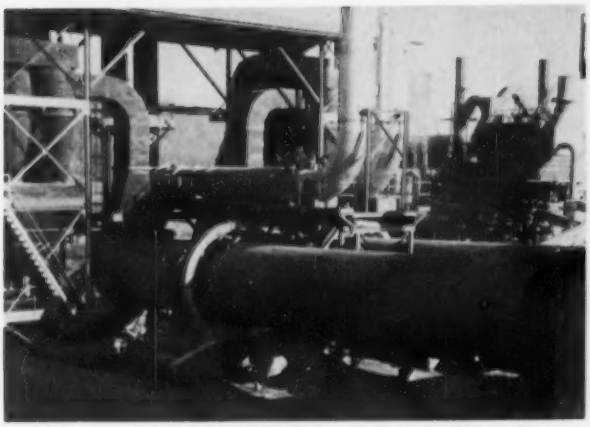
Practical means of reducing the consumption of ferro-silicon have been studied. Since nearly 45 pct of the total ferro-silicon is consumed in reducing trivalent iron to the divalent stage, it seemed logical to investigate more economical means of accomplishing this.

Addition of any type of reductant to the melting furnace feed has been approached with caution, because of possible danger of reducing metal in the furnaces. In the original design no provision was made for removal of metal.

Early attempts were made to add carbon, in various forms, to the ladling reactions, and thus reduce ferro-silicon consumption. None of these experiments proved successful. All resulted in either violent carbon boils or no significant reduction in ferro-silicon requirements.

After a time, it was found that some metal was reduced in the furnaces, in spite of the most careful operation, and a method was devised to remove this accumulation periodically. With this problem overcome, more latitude was available for attacking the problem of reducing trivalent iron before the addition of ferro-silicon.

At left, aerial view of the Riddle open-pit nickel mine. And below, ore dryers.



The most convenient place for the addition of carbonaceous reductant and for attaining intimate mixing appeared to be at the intake of the kiln. A test program was, therefore, initiated.

The first reductant tested was powdered coal. In order to minimize the possibility of metal reduction, the fixed carbon added was held well below that required for complete elimination of trivalent iron. In the tests, coal was fed to the kilns at a rate to provide 0.33 pct fixed C in the feed.

As expected, no reduction took place in the kilns because of the oxidizing atmosphere. The volatiles were removed from the coal, and some unburned carbon passed through with the calcined ore. In the furnaces approximately 50 pct of the trivalent iron was reduced. This reduced ferro-silicon consumption by approximately 15 pct. It was also found that electrode consumption was reduced by 10 to 12 pct.

Since sawdust is available locally, tests were made using it in place of coal. Results were improved. Again, no reduction took place in the kilns, and the cost per pound of fixed carbon was considerably less than when using coal. Savings in ferro-silicon and electrode consumption was comparable, and it was found that oil consumption in the kilns was reduced about 13 pct.

As a result of the above tests, plans have been made for a permanent installation to add sawdust to the kilns. It is estimated that the cost of the installation will be amortized in a relatively short period of time.

Smelter equipment

The major smelter equipment consists of seven electric furnaces, two ladle handling machines known as *skip mixers*, four remotely-controlled turn-tables, eight self-propelled ladle cars, 22 reaction ladles, 12 slag ladles, three overhead cranes, a pig casting machine, and miscellaneous auxiliary equipment.

Of the electric furnaces, there are four 14,000 kva units for melting ore, one 13,500 kva furnace for producing ferro-silicon, and two 2500 kva furnaces for refining ferro-nickel and preparing it for casting.

The melting furnaces are three-phase, open-top, hydraulically-tilted units, 26 ft 3 in. inside diam by 10 ft deep. They are covered by stationary hoods to provide dust control and to protect operating personnel from arc glare. A 33-in. refractory bottom with a shallow corbel section is provided. The remainder of the sidewall is not lined. Water cooling of the walls freezes ore to the shell, providing the necessary protection. The 40 in. electrodes are of self-baking type, controlled by balanced beam regulators and actuated by hydraulic cylinders. Since the ore is relatively non-conductive, the furnaces are normally operated at 465 v phase to phase, with electrodes spaced 80 in. center to center. However, voltages of 300 to 465 are available in nine steps. The furnaces are operated open arc to minimize reduction of metal during the melting process.

The two refining furnaces are standard three-phase, closed-top, 9-ton capacity units provided with

Table I. Average Analysis of Ore Delivered to Smelter, Pct

Ni	1.5
Fe	8 to 15
MgO	25 to 38
SiO_2	45 to 55
Al_2O_3	1 to 3
Cr	0.8 to 1.2
CaO	1 to 2

Table II. Average Analysis of Smelter Feed, Pct

Ni	1.60 to 1.70
Fe	10 to 15
SiO_2	45 to 58
MgO	24 to 32
Cr	0.8 to 1.2
Al_2O_3	1 to 3
Loss of Ignition	6 to 8

10 ft diam graphite electrodes. These furnaces are provided with swinging roofs, hydraulic tilt, and balanced beam regulators.

Melting and reduction

Calcined ore is fed to the melting furnaces by gravity from refractory-lined, 50-ton feed bins. Ore feed is directed by insulated stainless steel feed pipes located around the periphery of the furnace. Remotely operated visor-type gates, located in the feed pipes immediately below the feed bins, control the ore flow. Ore is fed to the furnaces almost continuously, with the exception of the period while a furnace is being poured. Normally, the molten pool contains between 145 and 185 tons of material.

Average power consumption per ton of molten ore produced in 1959 was 683 kw-hr, and electrode paste consumption was 10.0 lb.

The melting furnaces are operated as two parallel producing lines. Each line contains, in addition to the two furnaces, one skip mixer, two turntables, two reaction ladles, and two slag ladles. All of the ladles are mounted on self-propelled, remotely-controlled cars. Operating controls for this equipment are located in an air-conditioned control room and so placed that operators have a clear view of the equipment.

A typical reduction cycle is as follows:

1) Approximately 11 tons of molten ore, at 2940° to 3000°F, is poured from one of the melting furnaces into a 280-cu ft reaction ladle. The molten ore is weighed, as it is poured, by track scales set in the reaction-bay floor.

2) The ladle containing molten ore is positioned in one side of the skip mixer. In the other side of the skip mixer, an identical ladle is waiting with 9 to 14 tons of molten ferro-nickel.

3) The ladle containing ferro-nickel is raised by the skip mixer and its contents poured rapidly into the ladle containing molten ore. At the same time, $-\frac{5}{8}$ in. ferro-silicon is poured into the ladle, care being taken to have the ferro-silicon enter with the ferro-nickel, or *seed metal*, so thorough mixing and agitation takes place. Reduction is very rapid, and considerable exothermic heat is released.

4) The empty ladle is set down, and the full one, now containing the mixture of ore, seed metal, and ferro-silicon, is raised and rapidly poured into the empty ladle.

5) Pouring from ladle to ladle is continued as in step four for a total of five pours.

6) The ladle in which the mixture remains after the above pours is allowed to stand for a minimum of 3 min to promote settling of metallic particles.

7) A cast-steel slag ladle is positioned in the skip mixer opposite the full reaction ladle.

8) The full reaction ladle is raised and slag carefully decanted off the top of the metal. The operator is guided in the removal of slag by special indicating lights showing the angle of tilt of the ladle and also by a man watching for metal through cobalt-tinted glass.

9) The slag ladle is transported to the granulating position in the outer wall of the smelter building, and slag granulated by high pressure water jets.

While the slag is being poured in step 8, the other melting furnace is being poured in preparation for the next reduction cycle, and the ladle is positioned in the skip mixer as soon as the slag ladle has been removed. Another cycle is immediately started. The reaction cycle requires an average of 15 to 16 min.

Ferro-nickel, or seed metal, builds up in the system, normally 800 to 900 lb per reaction. This metal is weighed on the track scales at regular intervals. When the weight has increased sufficiently, normally to about 28,000 to 30,000 lb, a portion is removed or *thieved*. This is accomplished by pouring the metal through a small overflow ladle suspended from an overhead crane. Samples of metal are taken at this time for rapid analysis by spectrographic means for nickel, phosphorus, and silicon. These preliminary analyses are used as guidance in the refining process, as well as to control the nickel content of the seed metal.

Refining

Normally one heat of ferro-nickel for refining consists of two lots of thieved metal, each weighing 8000 to 9000 lb. Metal is transported to the refining furnaces by overhead crane.

Production contract with the US Government requires that ferro-nickel meet the specifications shown below:

Ni	Over 25 pct
P	Less than 0.05 pct
S	Less than 0.05 pct
C	Less than 0.20 pct
Cr	Less than 0.25 pct

Theived metal meets the above specifications in all respects except phosphorus. Therefore, refining consists only of dephosphorizing and deoxidizing.

Dephosphorizing includes the normal procedure of oxidizing the phosphorus to P_2O_5 with iron ore in the presence of a high-lime slag to form $Ca_4P_2O_9$. In this form it is skimmed from the furnace.

Since the phosphorus content of the theived ferro-nickel varies from 0.15 to 0.40 pct, it was found expedient to provide a table of lime and iron ore additions, for guidance of operating personnel. It is necessary at all times to maintain a slag high in lime and iron oxide with sufficient volume to result in a final slag containing 5.0 to 10.0 pct P_2O_5.

The steps in refining are as follows:

1) The first thieve of ferro-nickel is carburized with fine coke as it is poured into the refining furnace, bringing the carbon content up to about 0.25 pct.

2) Lime and iron ore are added in quantities dictated by the preliminary phosphorous analysis of the ferro-nickel and weight of the thieve.

3) The slag constituents are melted, after which only sufficient power is used to maintain fluidity until the second thieve is received.

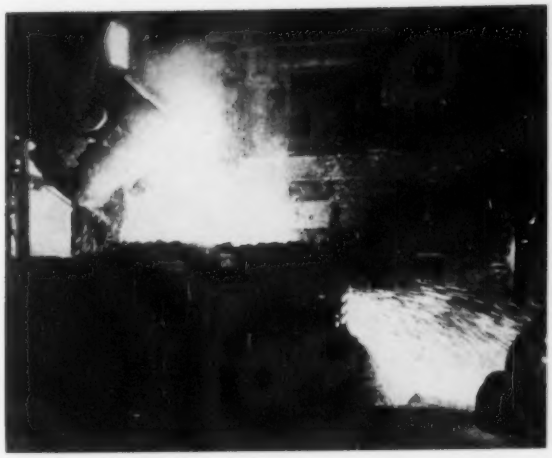
4) Slag is skimmed immediately and completely after receiving the second thieve.

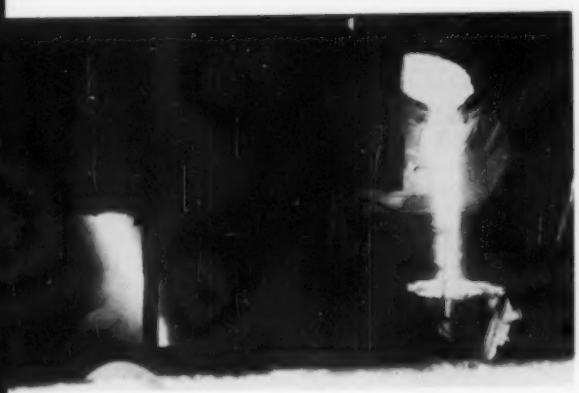
5) A second addition of slagging constituents is made, and the slag melted. The slag is held fluid for 10 to 12 min and a sample of the ferro-nickel is taken for preliminary phosphorus analysis by a Quantometer.

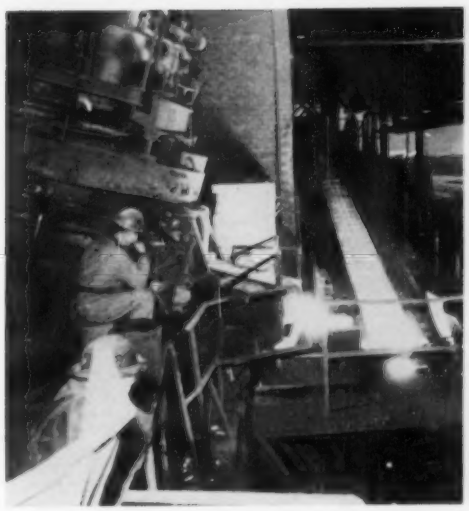
Table III. Average Analysis of Ferro-Nickel Produced in 1959, Pct

Ni	45.94
Fe	52.38
S	0.006
P	0.024
C	0.029
Cr	0.02
Si	0.9
Co	0.5
Cu	0.2

Below, pouring molten ore (left) and decanting slag (right). At right, charging a refining furnace. And below right, casting refined ferro-nickel.







6) The slag is carefully skimmed immediately after taking the preliminary sample.

7) A third addition of slagging constituents is made and held for 10 min, after which it is skimmed off very completely to prevent phosphorous reversion. This is an *insurance* slag.

8) A finishing slag is needed. This is made up of 30 lb of lime and 10 lb of fluorspar. After this addition, the power is increased to raise the bath slightly above casting temperature.

9) After the bath has been raised above casting temperature, ferro-silicon is added for deoxidation. Deoxidizing is accomplished in 3 to 5 min by the addition of 1.8 lb of 45 pct Fe-Si per 100 lb of ferro-nickel.

10) Immediately following deoxidation a sample is dipped for a flash test. A flash count of 45 sec gives an average casting temperature, into the casting machine, of 2700°F.

Casting

The 90-ft pig casting machine is mounted on tracks and can be positioned in front of either refining furnace. Ferro-nickel is poured directly from the refining furnaces into a small combined forehearth and runner, which directs the metal into the molds. The operator can easily synchronize the speed of the casting machine to the tilt of the furnace to produce pigs of even size. The average pig weight is 40 lb.

Pigs discharge from the casting machine into a water-cooled tumbler. In the tumbler, they are further cooled and, at the same time, any adhered mold wash and minor metal splatters are removed.

Conclusion

The Ugine process for the recovery of nickel from Riddle ores has proven satisfactory and economical. It is the first time the process has been used for large-scale, continuous operation.

During early stages of production, a number of mechanical and operational problems were encountered, as is to be expected in a plant using a new process. Most of these problems have been overcome, and the smelter is producing ferro-nickel at a rate nearly 25 pct above design capacity. The average analysis of the ferro-nickel produced in 1959 is shown in Table III.

Operating and production data for 1959 are shown below:

	Dry Tons	Pct. Ni	Lb. Ni
Total ore from stockpile	823,835	1.50	24,697,264
Hard rock rejected	142,871	0.64	1,825,847
Ore to process	680,964	1.68	22,871,417
Molten ore	604,231	1.809	21,866,252
Slag & tailings loss			1,833,661
Dust & unaccountable losses			233,662
Ferro-nickel produced	22,631	45.94	20,794,091
Recovery from ore to process			91.41 pct
Total power consumption per lb of nickel produced			26.32 Kw-hr

FERRO-NICKEL SMELTING IN NEW CALEDONIA

Built on an island of nickel . . . New Caledonia . . . a new electro-metallurgical ferro-nickel plant has recently been put in operation. This article describes the new installation, expected to produce 26 million lb of nickel annually.

The four nickel papers represented in this issue are but a sample of those delivered during the International Symposium on the Extractive Metallurgy of Copper, Nickel, and Cobalt, held during the Annual Meeting. Complete text and discussion of the five-session Symposium will be available by the end of the year as one of the continuing series of volumes published by Interscience Publishers, Inc., for The Metallurgical Society.

by C. G. Thurneyssen,
J. Szczeniowski,
and F. Michel

NICKEL ore found in New Caledonia is a hydrated silicate of iron and magnesia in which nickel replaces part of the iron and the magnesia. The analysis of this ore is given in Table I.

This ore does not contain nickel in the form of a definite mineral. It is deeply impregnated with nickel, and this peculiar constitution explains why all beneficiation attempts made thus far in specialized laboratories in Europe and the US, as well as those of Le Nickel, have not proved sufficiently satisfactory to warrant industrial application. Metallurgical treatment must, therefore, be carried out on unbeneficiated ore.

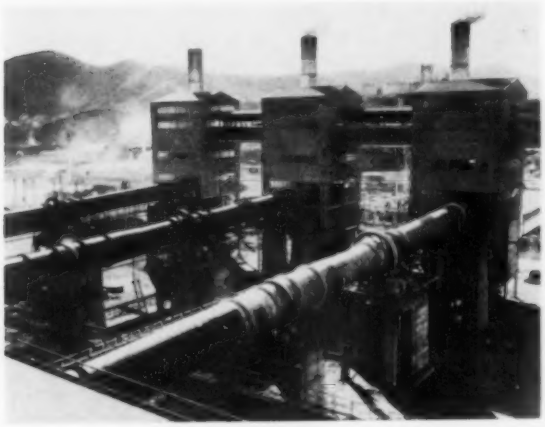
The analysis in Table I shows that this ore is rather poor in nickel . . . one short ton of ore contains only between 37 and 50 lb of nickel, with an average of 44.5 lb. Furthermore, it does not contain any valuable metals other than nickel and cobalt. Also, it is a highly refractory ore requiring high temperatures to smelt.

Two different metallurgical processes are now being used on this ore: the customary matte smelting process, and a new electro-metallurgical process which produces a refined ferro-nickel.

In the matte smelting process, in use for many years, the ore is first treated on Dwight Lloyd sintering machines. The sinter thus obtained is smelted together with gypsum in water-jacketed blast furnaces. This produces an iron-nickel matte, which is treated in horizontal converters in order to remove the iron. The nickel matte is sent to France where, after calcination, the resulting oxide is reduced with charcoal. The product is in the form of nickel cylinders which contain 99.6 pct Ni + Co.

C. G. THURNEYSSEN, J. SZCZENIOWSKI, and F. MICHEL are with the Société Le Nickel, headquartered in Paris. This paper was part of the International Symposium on the Extractive Metallurgy of Copper, Nickel, and Cobalt presented at the AIME's 1960 Annual Meeting.

The Doniambo ferro-nickel smelter in New Caledonia. Below, close-up of rotary dehydrating kilns.



The new process

The end product of the electro-metallurgical process is a refined ferro-nickel used (instead of pure nickel and with the same results) as a raw material in the making of special steels.

In order to treat the highly refractory nickel ores of New Caledonia, it was decided to make use of electric smelting furnaces. They could achieve the high temperatures required to smelt the ore without added fluxes and yet obtain a slag sufficiently fluid to permit satisfactory separation of the reduced metals. In order to apply the devised process, it was essential to procure the necessary electric power at reasonable cost . . . obtain a high nickel yield . . . and make use of the iron as well as the nickel content of the ore.

The electric power used in the new smelter is produced in two ways. The main source is the hydro-electric plant built on the Yaté river where adequate damming has created a regulating basin which contains 80,000 million gal of water. A 530-ft waterfall makes it possible to obtain an average of 340 million kw-hr per year. The other source of electricity is a new 25,500 kw power plant equipped with free piston engines, gas turbines, and alternating generators. It uses fuel oil, and is meant to supplement the Yaté plant in dry years and produce on its own 200 million kw-hr per year.

The electric smelter, intended to ensure a production of over 26 million lb of nickel contained in the ferro-nickel, has been erected to the north of the existing water-jacket plant. The new plant is situated along a lagoon, upon an embankment made with the slag from the older smelter.

The new smelter consists essentially of three shops used for:

Ore preparation, with three cement-plant-type rotary kilns to dry and dehydrate the ore before it is fed into the electric furnaces;

Smelting and reduction, with four 12,500-kva electric smelting furnaces which produce a 22 to 23 pct Ni crude ferro-nickel; and

Refining, with one Kalling rotary furnace for desulfurization and three lateral-blown, basic bessemer converters for removing carbon and silicon.

Ore preparation

Raw ore is brought from the stockyard to the entrance of three rotary kilns by means of a 1520-ft belt conveyor. Here it is dehydrated at 1300°F. By the time the ore has been heated to 230°F it is assumed that the moisture . . . representing between 20 and 30 pct of the weight of the raw ore . . . has been entirely removed. This is called dried ore. But the actual water content of the ore . . . amounting to 10 to 13 pct of the weight of the dried ore . . . begins to be expelled only at 900°F and has completely disappeared by the time 1300°F has been reached.

The ore discharge temperature of 1300°F permits adequate kiln operation with a good heat balance and yet keeps the ore from sintering. Sintering the ore at this stage of the process would hinder its flowing into the electric furnaces and tend to make the coke and ore mixture uneven. This temperature is also adequate to permit handling the ore in refractory-lined buckets, and feeding it into the electric furnaces while almost entirely recovering the heat content of the hot ore. The dehydrated ore averages 66 lb of Ni + Co per ton.

Each rotary kiln is designed to treat 730 tons of raw ore per day. This corresponds to 550 tons of dried ore and 458 tons of dehydrated ore. The kilns are 240 ft long with a diam of 9 ft in the drying zone and 10 ft 4 in. in the dehydrating zone. The linings of the kilns are high-pressure silico-alumina brick containing 25 to 30 pct alumina which withstands the abrasive conditions. The kilns have a slight downward slope towards the ore discharge end, and they lie upon four reinforced concrete arches about 30 ft high.

Heating is counter current to the movement of the ore. An oil burner is located at the discharge end. This burner can supply a maximum of 84 million Btu per hr. Fuel oil consumption is about 120 lb per ton of dry ore, but it may go up to 180 lb, if the ore is particularly moist. The burner is intended to produce a highly oxidizing atmosphere through the use of some 60 pct excess air. Flue gases and steam leave the kiln next to the ore inlet at a temperature of about 500°F. After passing

through a dust settling chamber and cyclones, the gases move to the stack through the exhaust system.

Once introduced into the rotary kilns, the ore moves progressively forward, warming as it goes and losing both its moisture and water content proper before being discharged into the brick-lined receiving hopper at the end of the kiln. This hopper is connected through a pneumatic register with brick-lined buckets. These buckets of 1000-gal capacity are equipped with removable bottoms for feeding the electric furnaces. They are transported, two at a time, to the electric furnace shop by a transfer car.

Electric furnaces

Dehydrated ore is fed into four 36-ft 6-in. diam Elektrokemisk electric furnaces through pneumatically-closing inlets in the cover. Each furnace has a nominal power of 10,000 kw and is designed for the treatment of 408 to 445 tons of dry ore per day. It can produce about 44 tpd of crude ferro-nickel containing 22 to 23 pct Ni.

The necessary power for smelting a ton of ore can be estimated at 550 kw-hr, with a very slight variation around this figure. The heat required to melt a ton of ore can be broken down as follows: heat for melting the slag, which represents 80 to 85 pct of the total; and heat for melting the metal and for reduction. These two quantities of heat vary inversely. With a higher content of nickel and iron in the ore, more metal is obtained and, while it requires more heat for reducing, it yields a smaller amount of slag. There is, thus, partial compensation.

The furnace efficiency, defined as the ratio of power required for smelting to the power actually used, is 75 pct. Feeding the furnace with preheated ore supplies about 510,000 Btu per ton of dry ore, which consequently saves about 200 kw-hr per ton.

The furnace transformers have a nominal power rating of 13,500 kva. The optimum voltage between the electrodes and the smelting bed is about 155 volts, giving an intensity of roughly 21,000 amp.

The electric furnaces are lined with magnesia brick (over which is laid a sole plate made of dolomitic puddled clay) and are equipped with a silico-alumina brick cover.

The electrodes are of the Soderberg type with a diam of 4 ft 1 in. They dip into the slag, and heat is evolved through the electrical resistance of the slag. Their level is automatically controlled in accordance with the conductibility of the slag. In order to obtain even heating of the charge, operation is set for maximum voltage. With regard to the Soderberg paste, the amount used per ton of ore amounts to about 4 lb.

Table I. Composition of Dry New Caledonian Nickel Ore, Pct[1]

Compound	From	To	Avg
Loss on Ignition	10	13	11.3
SiO_2	32	39	37
Al_2O_3	0.5	3	2.2
MgO	20	26	23
Fe_2O_3	15	22	20.2
Cr_2O_3	1	3.5	2
CaO	0.1	0.8	0.3
MnO	0.2	0.8	0.3
NiO + CoO	3.5	4.1	

[1] Moisture accounts for 20 to 30 pct of the wt of raw ore.

Furnace operation

The third floor of the reduction plant is the feeding floor, where furnace throats are set in a circle under the handling telpher for the buckets. These throats are connected to nine feeding holes in the furnace cover by stainless steel pipes kept full of ore.

The brick-lined buckets described above can be placed on the furnace throats, and through an opening in the bell-shaped lower part (Staehler type), they make it possible to feed the ore into the furnace without further handling. These buckets are set in place by telphers, which can raise up to 15 tons at a rate of 80 ft per min. Seven buckets per hr can, thus, be fed into each furnace. For the four electric furnaces, four telphers have been provided to feed them from three separate locations on the ground which correspond to the transfer cars of the three kilns.

The reducing agent, used by the Doniambo smelter is coke breeze screened to between 2/5 in. and 1 2/5 in. The amount of fixed carbon added to the ore varies between 63 and 74 lb per ton of dry ore. Coke breeze is put into the buckets while they are being carried on the transfer cars; it is automatically weighed in a recording weighing hopper before it is placed in the ore bucket.

The physical and chemical composition of the ore, of course, has a direct bearing on furnace operation. First of all, the regularity with which it is possible to feed the furnace, and the voltage to be chosen for a given power are both affected by the screen analysis of the ore. A fine ore needs a higher voltage for smelting than does a bulky one. And if there are both large and fine particles, the ore is more likely to fall under the electrodes, thereby causing an interruption in the flow of electricity.

From a chemical point of view, the silica: magnesia ratio of the ore is also very important, for it affects the melting point of the slag. This point is also affected in the same way by the percentage of FeO, which governs the silicon content of the crude ferro-nickel. Moreover, the presence of iron oxide in the slag improves its conductibility. It will, therefore, be understood that in order to ensure regular operation and obtain a constant composition of the crude ferro-nickel, it is necessary to strive for a constant content of iron oxide in the slag. This is not always easy to maintain when the ore composition varies, and may necesitate changing the amount of reducing agent used.

Crude ferro-nickel is tapped at a temperature of about 2750°F, while the slag attains a temperature of 2900°F. The composition of the crude ferro-nickel is as follows:

20 to 23 pct Ni+Co, (This content depends upon the Ni:Fe ratio of the ore, and, for a given ore composition, on the extent of reduction)

2 to 4 pct Si, (If the crude ferro-nickel has a high silicon content, it is more fluid and the ladle can then be completely emptied, since the melting point of the ferro-nickel is lower.)

1.8 to 2.2 pct C, (Carbon also has a well-known bearing upon the melting point of the crude ferro-nickel, but the variation of C is limited.)

1.5 to 1.7 pct Cr, 0.25 to 0.35 pct S, and 0.02 to 0.04 pct P.

Crude ferro-nickel heats of about 10 tons are tapped directly into the Kalling rotary desulfurizing furnace every 2 hr. For the slag, the electric furnaces are provided with two tap holes, which are used in turn. The slag is granulated in troughs and sent—together with the granulation water—into receiving sumps from where it is pumped as slurry to the coast.

The tapping shop located at the opposite side of the ore inlet receives the heats from the four Elektrokemisk furnaces. It is on a line with the refining workshop and uses the same cranes: two 22-ton and one 55-ton. This is the area in which the tapping ladles are lined and preheated.

Refining

The crude ferro-nickel produced in the electric furnaces is refined in two separate operations: first, sulfur removal; second, oxidation of chromium, silicon, carbon, and part of the phosphorus.

Sulfur removal: This was, at first, done with lime in a 10-ton electric-arc furnace in the manner customarily used for steelmaking. At present, the removal of sulfur is accomplished in a rotating furnace with finely-granulated burned lime, in accordance with the process set up by Professor Kalling. This is a very efficient process that makes possible the lowering of sulfur content from 0.25-0.35 pct to 0.02-0.03 pct, without adding heat.

Oxidation: Removal of chromium, silicon, carbon, and part of the phosphorus is done in three 10-ton lateral-blown converters lined with magnesia-chromium brick. Air is supplied by volumetric blowers of the Roots type, which provide 5500 cu ft per min.

Chromium and silicon are easily oxidized. Carbon is also eliminated without difficulty, even more so since its removal gives a gaseous product. As regards phosphorus, the oxidizing capacity of the slag facilitates its partial removal, bringing the phosphorus content down to between 0.02 and 0.03 pct.

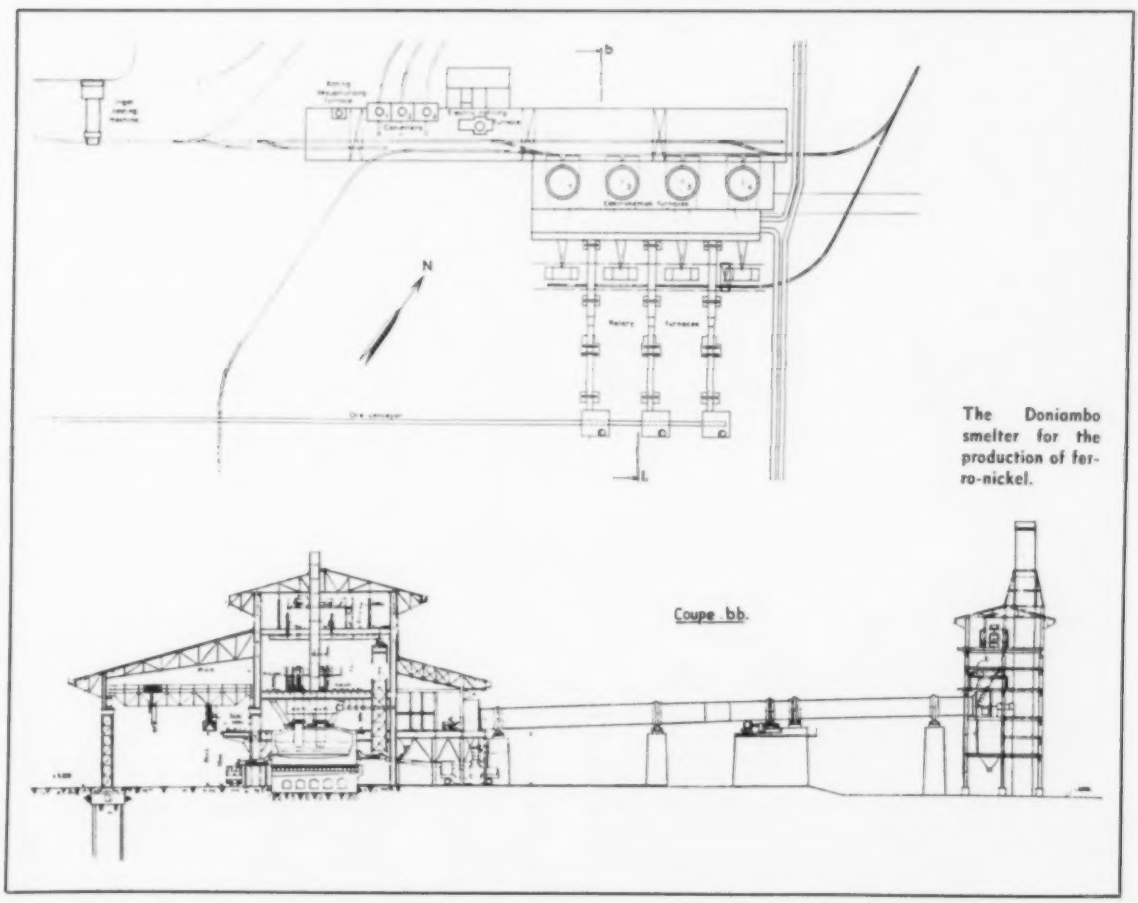
The refined ferro-nickel is tapped at a temperature ranging between 3000° and 3100°F and transferred by ladle to the ingot machine where it is cast into ingots weighing between 40 and 60 lb.

Slag from converters is poured into slag cars and transported to the embankment, for its nickel content is too low to warrant resmelting. However, the slag which comes from the Kalling furnace is sent to the water-jacket smelting plant to be added to the charge of the matte furnaces.

Finally, the ferro-nickel ingots of the analysis shown in Table II are trimmed and prepared for shipment to customers.

Table II. Composition of Refined Doniambo Ferro-Nickel, pct

Ni + Co	S	Si	C	P
24.06	0.021	0.028	0.021	0.024
24.42	0.024	0.028	0.029	0.023
26.06	0.023	0.027	0.024	0.023
27.12	0.022	0.023	0.021	0.019



The Doniambo smelter for the production of ferro-nickel.

ACID LEACHING MOA BAY'S NICKEL

Pressure leaching of nickeliferous laterites by sulfuric acid is the key to the utilization of ores at Moa Bay, Cuba. This is a description of operations at Freeport Nickel's new plant in Cuba.

by E. T. Carlson and C. S. Simons

THE existence of vast lateritic ore deposits in Cuba has been known since the end of the 19th century. Many attempts were made to produce marketable products from these deposits in the early post-discovery years, but without notable success. Interest in the deposits lagged until the late 1930's when Freeport Sulphur Co., the parent company of Moa Bay Mining Co., acquired a number of mining concessions on the northern coast of Oriente Province, near the towns of Mayari and Moa. Exploration work at that time was concentrated on the Mayari area, and a large deposit of mixed iron and serpentine ores averaging 1.46 pct Ni was found—an island of high-grade ore in a sea of much lower grade material. In the course of a metallurgical development program Freeport tested a number of possible processes for recovering nickel from the mixed-type ores. This work formed the basis for the establishment of the Government-owned plant at Nicaro, Oriente. The Nicaro development has been described in numerous articles which have appeared in the technical press.[1, 9, 12]

After the start of the Korean war, Freeport began intensive prospecting near the town of Moa, 40 mi east of Nicaro. This program uncovered over 50 million tons of nickeliferous laterite averaging about 1.35 pct Ni, 0.13 pct Co, and 46.5 pct Fe. These deposits differed from the ores in the Nicaro area in two significant ways: 1) the Moa ores contained about twice as much cobalt as those at Nicaro; and 2) there was little of the silicate type *serpentine* ore at Moa.

The low magnesia content of the Moa Bay ores suggested reconsideration of acid leaching techniques which could not be applied to the high-magnesia Nicaro ores. Bench-scale laboratory work indicated that a high-temperature leach with sulfuric acid offered considerable promise. Operation of a 10-tpd leaching pilot plant at Hoskins Mound, Tex., and the operation of a completely integrated 50-tpd pilot plant at Port Nickel, La., furnished the data upon which the design of the Moa Bay facilities was based.

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The nickel-bearing lateritic iron deposits at Moa Bay occur as a surface mantle of reddish-brown soil, varying from 10 to 100 ft in thickness. Favorable topography with adequate sub-surface drainage has been largely responsible for the development of the higher grade areas which are located on a series of gentle terraces extending inland some 3 mi from the coast.

Iron laterite has a clay-like consistency and a relatively high moisture content which ranges from 25 pct near the surface to 40 pct at the bottom of the ore column. The ore as mined at Moa Bay averages about 85 pct −325 mesh, a major part in the range of 5 μ. The balance of the material consists of ⅛ to ¼ in. iron concretions, low in nickel and cobalt, and a few erratics of undecomposed serpentine.

Table I. Slurry Plant Feed. Typical Screen Analyses and Composition of Screen Fractions

Mesh Size:	+20	−20 +35	−35 +65	−65 +150	−150 +325	−325
Weight, Pct	5.5	1.5	2.1	2.5	3.4	85.0
Analysis, Pct						
Ni	0.43	0.68	0.89	1.01	1.22	1.44
Co	0.05	0.25	0.28	0.42	0.29	0.12
Fe	46.2	38.1	32.4	33.7	37.1	48.6
Al	8.4	9.9	8.8	8.4	6.3	4.8
Mn	0.52	1.10	1.86	2.10	1.84	0.60
Mg	1.5	2.1	2.0	1.9	1.5	0.56
Cr	1.66	2.12	2.67	3.83	5.53	1.46

Table II. Leaching Operation. Typical Analyses of Ore, Residue, and Liquor

Element	Analysis of Solids, Pct		Extraction	Analysis of Liquor, Gpl
	Ore	Residue		
Ni	1.35	0.060	95.8	5.95
Co	0.146	0.008	95.1	0.64
Fe	47.5	51.0	0.36	0.80
Al	4.5	4.30	11.1	2.30
Mn	0.76	0.43	57	1.98
Mg	1.00	0.35	60	2.76
Cr	2.01	2.10	3.2	0.30
Cu	0.024	—	100	0.11
Zn	0.040	—	100	0.18
SiO_2	3.70	3.52	11.6	2.00
SO_4	—	8.06	—	66.9
H_2O	12.50	3.23	—	—
Free acid	—	—	—	(27.9)

Exploration work at Moa Bay started early in 1952 with a reconnaissance program. By the end of 1955, reserves amounting to more than 50 million tons having an average content of 46 pct Fe, 1.36 pct Ni, and 0.13 pct Co had been proved.

The character of the ore is such that separation of the material coarser than 20-mesh is all that is required to prepare a material suitable for acid leaching. Table I shows a typical screen analysis of screening plant feed, and typical chemical analyses of the screen fractions. Although the weight distribution within the screen fractions shows rather wide variations depending on the area being mined, the analysis within the narrow size fractions shows remarkable constancy. For example, the quality of *sands* (− 20, + 150 mesh) may vary from as little as 1 or 2 pct to as much as 10 or 12 pct; however, the break between *barren* material, (less than 1 pct Ni and 0.1 pct Co) and ore always occurs in the range of 20 to 35 mesh. Preparation of leaching feed, thus, requires only clean screen separation at 20 mesh.

Slurry preparation and handling

The process steps used at Moa Bay to prepare a *shipping concentrate* of nickel-cobalt sulfide from the iron laterite have been described in some detail in recent publications.[2, 6, 12, 15] Some of this information is repeated here to clarify the discussion of the leaching and sulfide precipitation operations, which are the primary concern of this paper.

The preparation of suitable leaching plant feed from ore delivered from the mine is done by slurrying in water and wet screening at 20-mesh. The flow sheet of this operation is shown in Fig. 1.

Ore from trucks or storage pile is fed into the slurry plant proper by apron feeder and inclined belt. A shaking grizzly with 5 in. bar spacing scalps off the stray rock, and the undersize goes directly to the log washers. The slurry with 25 pct solids overflowing the log washers is finished by two stages of screening, with primary screens having $\frac{3}{8}$-in. openings to protect the 20-mesh secondary screens.

The 5-in. oversize from the shaking grizzlies is scrubbed free of ore in a cylindrical scrubber; the oversize rock is crushed in a jaw crusher and combined with the vibrating screen oversize for disposal. This reject is carried by belt conveyors to a mined-out disposal area adjacent to the plant.

Raw ore slurry is moved by gravity pipeline to the main plant where it feeds into an elevated splitter-box, from which it can be fed through siphon feed pipes to either or both of two 325-ft diam storage thickeners. Each of these tanks furnishes ore slurry storage for three to five days of full-rate plant operation.

The ore slurry, fed to the thickeners at 25 pct solids is settled to above 45 pct solids to provide feed for the leaching operation. Overflow water is recirculated to the slurry preparation plant by two-stage centrifugal pumps.

The critical step in the process is the selective leaching of the nickel and cobalt from the predominant gangue fraction. The ore is entirely mixed oxides; sulfides, sulfates, and carbonates are absent.

No nickel or cobalt minerals have been positively identified; they occur to some extent in the spinels (cobalt more than nickel), but the major part appears to be associated with the goethite. There is considerable evidence that the nickel is part of the goethite lattice.

Selective leaching investigated

Under normal laboratory conditions, the great bulk of this ore is soluble in mineral acids. No selectivity is apparent in the rates of solution of the various components up to the normal boiling point. Successful leaching of these lateritic ores, thus, requires special conditions.

It is generally known that above some temperature, which is characteristic of the metal ion involved, the sulfate salts become less soluble as the temperature is increased. These characteristic temperatures for ferric iron and aluminum on the one hand and for nickel and cobalt on the other might possibly be such that a temperature range permitting selective solubility exists. There is no reliable high-temperature solubility data for nickel or cobalt sulfates known to the authors. However, the ferric sulfate-water system has been reported in detail by Posnjak and Merwin.[5] As expected, the solubility of iron becomes quite small at 392°F, the highest temperature investigated.

Initial investigations were made in the region of 400°F. While it was found that good nickel and cobalt extractions were possible—that is, their solubility was high enough to support the necessary concentrations—selectivity was not as good as desired (that is, acid consumption by iron and aluminum was rather heavy) and extraction rates rather

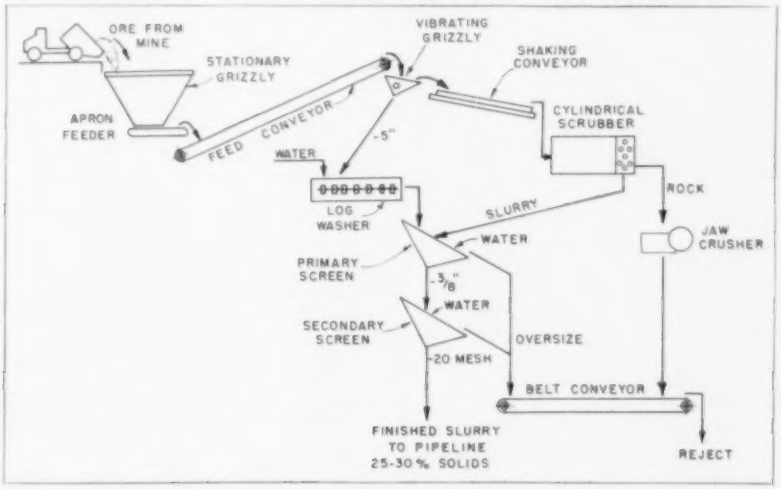

Fig. 1—Slurry preparation system at Moa Bay, Cuba.

slow. The important point, however, was that it was possible to extract the nickel and cobalt without adding the acid equivalent of the iron. This implied that higher temperatures might give greater selectivity.

The implication of further process improvement with increasing temperature proved to be true. Extensive laboratory investigation established the optimum temperature region as lying between 450° and 500°F, where excellent nickel and cobalt extraction(95 pct or better) at low acid levels and treatment times was obtained.

Rate of extraction considered

To apply these results to economic commercial extraction of nickel and cobalt, the rate of extraction, as determined by operating conditions, must be known with reasonable accuracy, since this determines the requirement for reactor volume. During early work it was found that unless leach extractions were at least 85 to 90 pct, the leached residue settled very poorly. This practical limitation dictated that extractions had to be better than 85 pct. It was also found that in this region the extraction reaction is *first order*, i.e., that rate of extraction at any instant is proportional to the concentration of some single limiting reactant at that instant. In the case of acid leaching of Moa Bay ore, the controlling concentration was found to be that of nickel remaining in the ore solids.

A discussion of methods used to determine the parameters of the rate functions is beyond the scope of this paper. But these methods were applied to a pilot system dimensionally and mechanically similar to the commercial one. This has the important advantage of eliminating certain variables (e.g., agitation level) which might have some influence on results. The effect of acid level and temperature on extraction rate were determined. Typical extraction curves are shown in Fig. 2, where extraction as a function of batch hold time is plotted for several possible sets of operating conditions.

Satisfactory interpretation of the leaching rate studies required the postulation that the nickel occurs in at least three mineral species. Under conditions in the practical operating range, leaching is very rapid from one of these, considerably slower for a second (and this is the rate that determines extractions), and very, very slow for the third. About 60 pct of the nickel is contained in the rapidly leached fraction, and 3 to 4 pct in the refractory fraction. This distribution may be of considerable importance in interpreting results of the commercial operation. It is the author's opinion that the rapidly leached 60 pct (which was remarkably constant in the rate studies, and showed no correlation whatever with treatment conditions) is associated with the goethite fraction of the ore. From the work previously cited,[5] we know that our treatment conditions are around 200°F above the temperature at which goethite becomes unstable; threfore, very rapid conversion is probable. That leaching is attendant to this conversion is evident from the fact that much poorer extractions are obtained from ore previously roasted for dehydration than from unaltered ore. For example, conditions that yield 95 pct extraction from raw ore give only 80 to 85 pct extraction from pre-roasted material. The solubility curves for hydrated ferric oxide, extrapolated from the lower temperatures, show a high iron solubility. It seems probable, then, that the transition from hydrous to anhydrous ferric oxide involves passing through a solution phase.

A comparison of the analyses of the leached residue with the raw ore feed is shown in Table II.

The final weight of leached material averages about 93 pct of that of the ore fed; this gives the *extraction* figures shown in the third column. With 45 pct solids feed to the leaching reactors, the final slurry contains about 30 to 33 pct solids. At 30 pct solids, the leach liquor has the typical analysis shown in the fourth column.

Plant leaching operations

Translation of the process data described above into commercial operation on an economic scale posed many problems. As has been shown, successful operation requires temperatures in the 450° to 500°F range, with equivalent pressures between 400 and 600 psi. Economically attractive operation calls for minimum production of 50 million lb of refined nickel per year, and this was the design rate selected. At 90 pct overall recovery, about 2 million tons of ore per year must be fed to the leaching system. On a 365 day year, this is equivalent to about 5500 tpd. Both ore settling and slurry flow characteristics limit feed density to about 45 pct solids. This means a slurry feed rate or about 1400 gpm, which, at reaction conditions, becomes about 2300 gpm due to thermal expansion and addition of condensate from direct heating. Batch hold times of about 90 min are required to attain 95 pct extraction. With the additional volume required to obtain batch results in a continuous system, and adding freeboard necessary in agitated vessels, the actual volume requirement becomes about 40,000 cu ft.

To get this volume into vessels of practical size, and at the same time provide flexibility and continuity of operation, the leaching system was split

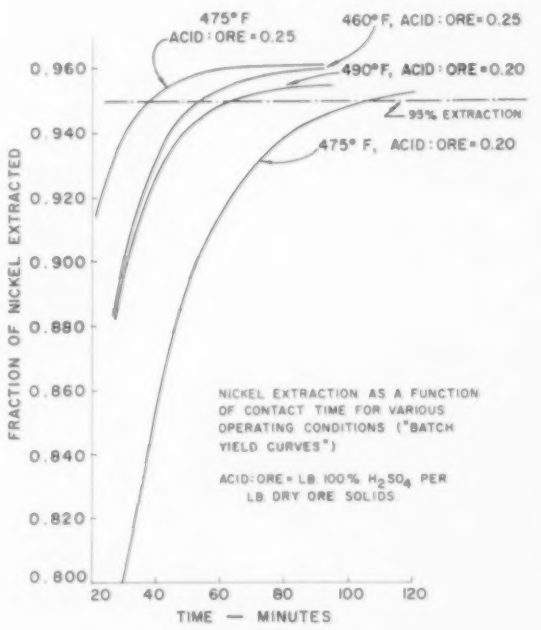

Fig. 2—Leaching of lateritic ore with sulfuric acid.

into four identical *trains*, each with four vessels in series. The flow sheet for the leaching system is shown in Fig. 3.

Raw ore slurry, at the maximum density that can be prepared and handled, is pumped from the storage thickeners. It goes through preheaters, where it is heated to 160° to 180°F by direct absorption of 15 psig steam, into mechanically-agitated storage tanks. There are two of these with a total capacity equivalent to about 4 hr operation at design rate. The slurry is picked up by rubber-lined centrifugal booster pumps, fed to the high-pressure slurry feed pumps, and pumped into the slurry heater tower of the reactor train. It is heated to reaction temperature, again by direct steam absorption, and flows by gravity through the four stages of reaction vessels. Sulfuric acid at 98 pct concentration is fed into the first reaction vessel with plunger pumps. Agitation is provided by the *Pachuca principle*, using high-pressure steam to induce circulation. Since very little of this *agitation steam* condenses, it is drawn off the reaction vessels and used, with the necessary makeup, to heat the feed slurry in the slurry heater.

The leached slurry overflowing the fourth stage reactor passes through an exchanger where it is cooled and its sensible heat recovered as 15 psig steam. It then passes through special flow-control chokes into a flash tank. The steam generated (at atmospheric pressure) in the flash tanks is used to preheat liquor at another step in the process. The leached slurry flows by gravity to the washing system.

Problems encountered

The means of carrying out these operations on a large scale with the reliability necessary for economic success presented a number of real problems. These fell into the following general categories: a) Pumping, particularly pumping slurries at high pressures; b) Agitation; c) Heat exchange; and d) Flow control.

The problem of construction materials and its solution has been discussed in considerable detail elsewhere,[8, 9, 10] and will only be touched on here, as may be required to clarify other discussion.

a) High Pressure Slurry Pumping

The solution to the problem of pumping the feed slurry into the reaction system was essential to the success of the project. There are several low-capacity pumps available commercially which are capable of pumping the viscous slurry at discharge pressures above 500 psi. However, the types of slurry pumps available in the capacity range required did not stand up in service

Freeport undertook an extensive development program in cooperation with two manufacturers of high-pressure diaphragm pumps, and, later with a major oil company. The results of this work were two diaphragm pumps of somewhat different type, each with 250 gpm capacity, and a modified oil-field diaphragm slush pump of 500 gpm capacity. The latter pump was selected for leaching feed service.

Two of these pumps (one spare) were put on each leaching train. They are double-acting duplex pumps, driven by non-condensing steam turbines that exhaust to the 85 psig service main. "Modification to the usual slush pump design" means that the slush pump was converted to a diaphragm pump by adding four diaphragm chambers. The pump operates on oil, which operates through the diaphragm on the slurry. The diaphragms themselves are cord-reinforced rubber of the same general shape as automobile tires. The principal problem in the development of this pump was the means of controlling the volume of oil in each pump cylinder. Since a reliable automatic system has been developed, diaphragm life is excellent.

The high-pressure pumps are pressure fed. For this service rubber-lined centrifugal pumps have proved satisfactory. Several makes were found to perform adequately in pilot plant tests, once the proper rubber formulation was established.

b) Agitation

Agitation is necessary not only to mix the reacting components, but also to insure uniformity of suspension so that the sandy fraction of the ore does not settle out. The problem of agitating this reaction system centers on the difficulty of providing mechanical agitation in large pressure vessels. For high-pressure service (600 to 750 psi), maximum economy is obtained at a length to diameter ratio of about 5:1. For vessels the size necessary for leaching at Moa Bay (10 ft diam by 50 ft high), mechanical agitation seemed out of the question. The use of draft-tube circulation, with steam as the motive fluid, promised to avoid the many problems inherent in mechanical agitation. Light gage titanium sheet could be rolled into a draft-tube and supported in the vessel. There is no seal problem, and there are no moving parts. The fed slurry has to be heated, and because of its viscosity, direct steam absorption appeared to be the only feasible means of doing this. Thus, the steam used for agitation could be drawn off the reaction vessels and condensed in the relatively cold feed slurry.

The adequacy of this proposed method of agitation was thoroughly checked by piloting. It was shown that sand dropout could not occur as long as steam flow was maintained. It was also shown that the slurry flow through the vessels (the staging or age-time function) was at least as good as in perfect mechanical mixing. Although no extensive investigation of the influence of agitation level on leaching rate was made, it was shown that leaching rates with draft-tube agitation were as good as mechanical agitation at reasonable power levels. As a result of this work, the draft-tube method of agitation was adopted, and no problems in connection with it have arisen.

c) Heat Exchange

It was mentioned above that the feed slurry to the leaching system is heated to reaction temperature by direct absorption of steam. The extremely high effective viscosity of the raw ore slurry eliminated any real possibility of heating it by indirect means. Tests showed overall heat transfer coefficients of only 30 to 40 Btu per hr per sq ft per °F for indirect heating 45 pct solids slurry with condensing steam. However, this same slurry viscosity makes direct-contact heating with commercial tower packings just as difficult. Raschig rings, grid tile, and cascade-type *cone and doughnut* packings proved to be completely inapplicable. Finally, a special packing, fabricated of expanded metal lath, was developed which has proved completely satisfactory. It gives good contact between vapor and slurry and does not tend to plug up. This packing is now in use, both in the atmospheric preheaters and the high-pressure heating towers.

There are two good reasons for cooling the leached slurry before flashing it to the atmospheric pressure. One is that it contains a very large amount of valuable heat. The second is that control of the flashing operation is greatly simplified if this heat energy is removed.

The heat must be recovered in useful form, preferably as steam. The possibility of stagewise flashing was studied carefully, but practical difficulties eliminated this solution. At operating conditions, the effective viscosity of the leached ore slurries is on the order of 5 centipoises. This characteristic suggests that the slurry might be cooled with conventional heat exchangers. Tests were run in the pilot plant on this method. The hot slurry was passed through the tubes of the exchanger, and steam at 15 psig generated in the shell. Good heat transfer was obtained. As a result of this work indirect exchange with generation of 15 psi steam was adopted to cool the slurry. Based on this work, an overall heat transfer coefficient of 350 Btu per hr per sq ft per °F was used for design. The commercial exchangers have been more efficient than expected. Thus, the present experience shows effective overall coefficients of 500 to 600 Btu per hr per sq ft per °F. Slurry leaves the coolers substantially below the 275°F design temperature.

Because of the corrosive environment, only titanium can be used in contact with the slurry. This includes tubes, tubesheets, and channels. To save material weight, special fabricating methods were used. Size and other limitations led to the use of two coolers on each leaching train. Each exchanger is a four-pass, floating head type unit. To avoid erosion of the titanium, the slurry velocity must be limited. Pilot plant experience showed 6 ft per sec to be a safe maximum, even in the first pass where high temperature makes erosion most likely. For additional safety, more tubes are used in the first pass where velocity is limited to 4 ft per sec. Tubes are ¾ in. OD, 0.065-in. wall of titanium in the A-55 grade. The exchanger shells are kettle type, and the units generate 25,000 to 30,000 lb of 15 psig steam per hr. This goes into service mains for use in other sections of the plant.

Table III. Countercurrent Decantation. Typical Analyses of Process Streams

Element	Raw Liquor to Neutralization, Gpl	Sludge to Waste	
		Liquor, Gpl	Solids, Pct
Ni	4.28	0.08	0.054
Co	0.46	0.008	0.007
Fe	0.58	0.011	46.8
Al	1.66	0.03	3.86
Mn	1.42	0.03	0.39
Mg	1.98	0.04	0.31
Cr	0.22	0.004	1.88
Cu	0.08	—	—
Zn	0.13	—	—
Ca	0.10	—	2.26
SO_4	47.1	0.91	12.7
H_2O (bound)	—	—	4.9

d) Flow Control

Now consider the problem of controlling the flow of the leached slurry. Each pound of this material at 475°F and 525 psi contains about 250 Btu (above its normal boiling point) of heat energy plus 1250 ft-lb of potential energy. At normal rate, this is equivalent to about 225 hp per train in potential energy, and 35,000 hp per train of thermal energy. Under normal conditions of *free* expansion, of course, very little of this heat energy is converted to mechanical energy. In expanding through a flow-control restriction, however, the conversion is greater, and it is capable of imparting extremely high velocities to the liquid. No material in any valve design was found that could stand this service for more than a few hours. If the slurry is cooled to 275°F, about 75 pct of the thermal energy is removed, and the velocities through the flow control device are much lower. The service is still extremely severe. However, by using on-off valves of a special design (so that the pressure drop is taken over a choke section rather than through the valve port) flow control is achieved. With cooled slurry, chokes of fused alumina ceramic give good service. Only very moderate choke wear is experienced in weeks of operation.

The actual flow control system used on each cooler discharge involves a single open choke capable of passing about 90 pct and, in parallel with it, an off-on valve capable of passing about 20 pct normal flow. The off-on valve is controlled by a radiation-type level instrument mounted in the fourth stage reactor.

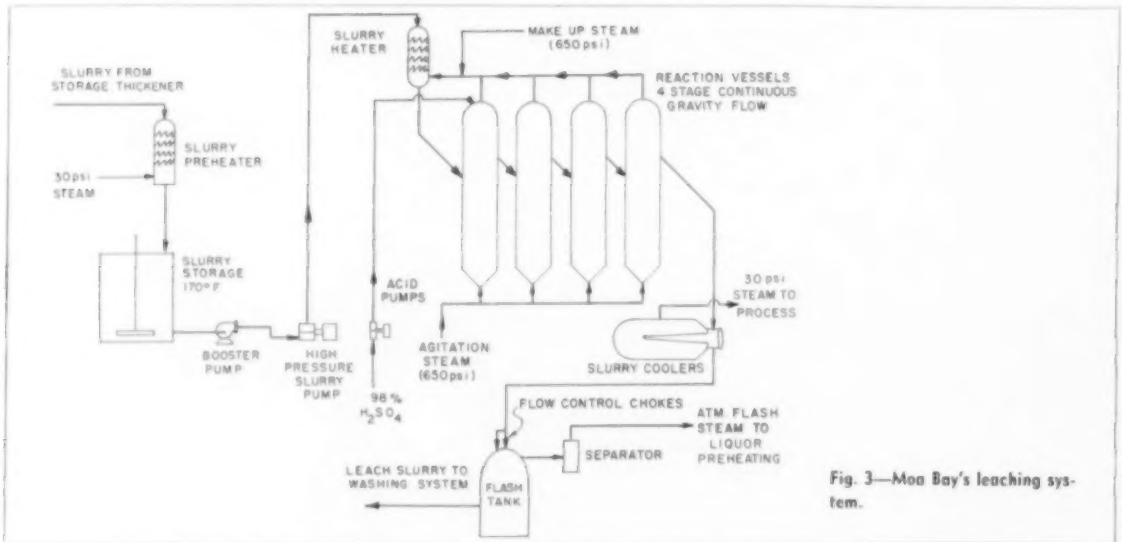

Fig. 3—Moa Bay's leaching system.

Special block valves are used on the high-pressure leached slurry lines upstream of the coolers. These are Y-type with cast titanium bodies and replaceable titanium seat ring and disc. The seat ring and disc are nitrided for hardness. Since these valves are used only for emergency closure, ceramic trim is not required. At 275°F and below, Alloy 20 has satisfactory corrosion resistance; below 210°F type 316 stainless steel is useful. This piping and valves downstream of the slurry coolers can be of design and material that are generally available.

The main problem in the control of the reaction is the proportioning of acid and ore. As described earlier, the acid:ore ratio is the principal variable determining the results. It is also a major item of controllable cost. Actual proportioning is done through stroke counters on the slurry and acid feed pumps. These are recalibrated periodically to insure accuracy. A quick operating check of leaching efficiency is available as a result of the fact that the settling rate of the leached slurry is a function of leaching efficiency. Observing the settling of a grab sample of product immediately tells whether leaching is going satisfactorily.

Concentrate precipitation

The preparation of a high-grade concentration from the dilute leach liquor is the second important phase of the Moa Bay operation. This involves a) separating the liquor from the barren solids; b) adjusting its composition; and c) treating it to precipitate the concentrate.

Stagewise pH adjustment was investigated originally as the means of precipitating a concentrate of nickel and cobalt. This posed many problems, primarily due to the fact that *clean* precipitates in the various pH ranges are almost impossible to obtain, and complex schemes for recycling filter cakes would be required to obtain acceptable quality of product and recovery of valuable metals.

About this time, Chemical Construction Co.'s research group established the fact that nickel and cobalt could be precipitated from acid solutions as sulfides.[6, 7] After considerable investigation during which Chemico's basic idea underwent radical changes, a method of preparing a sulfide concentrate was adopted which gave a very high recovery as a high quality concentrate, and at the same time rejected the most troublesome of the interfering metals.

Preparation of the liquor for the precipitation steps required removal of the free acidity after separation of the barren solids. The flow sheet for these operations is shown in Fig. 4.

a) Decantation

A six-stage counter-current decantation system was adopted as the best means of separating the leach liquor from the barren solids. These settle quite readily to a density of 55 to 60 pct solids, and can be thoroughly washed with relatively little dilution. Design calls for recovery of 99.5 pct of the soluble values with a net dilution of about 35 pct. The thickener unit area required is 7 sq ft per ton per day, which gives a unit of 225 ft diam. Because of the temperatures expected in the slurries, the first two stages use concrete tanks lined with acid brick over an asphaltic membrane. The tanks of the last four stages have concrete ring walls, protected by acid brick at the solution level, and waterproof asphalt-paved bottoms. The thickener mechanisms must be acid-resistant. A special type of traction mechanism was chosen. This machine supports the rakes on rubber-covered posts and thereby avoids the requirement for an expensive submerged structure.

The analyses of the materials produced by the washing system are shown in Table III. The analyses of washed solids and the associated liquor are based on a density of 57 pct solids. The washed slurry underflowing the sixth stage CCD tank is diluted with enough water to make it easily pumpable; it is transferred to an impounding basin.

b) Liquor preparation

The pregnant solution off the first CCD stage is pumped to the neutralization section where the free acidity is removed by treatment with coral mud. This mud is dredged from the inside of the offshore reef. It is barged to the preparation plant in the dock area, where it is slurried in fresh water, screened free of trash (−20 mesh) and water-washed in two stages to less than 500 ppm of chloride. The washing stages also provide for thickening of the slurry. It

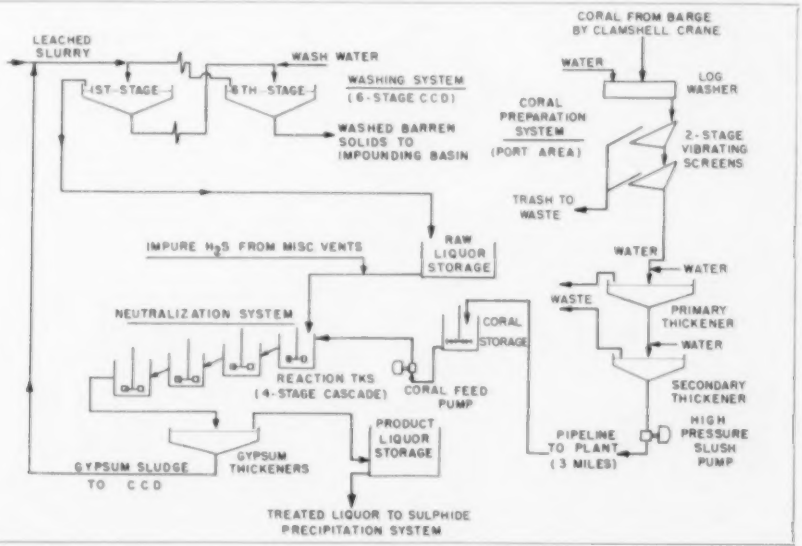

Fig. 4—Liquor recovery and neutralization system.

settles to about 40 pct solids and is pumped over 3 mi to the plant. The washed coral analyzes better than 90 pct $CaCO_3$, and its porous nature makes for rapid reaction with the free acid in the liquor.

In the neutralization section of the plant, the raw liquor is pretreated with waste hydrogen sulfide to destroy chromate chromium and reduce some ferric iron to the ferrous state. This reduction would have to be done in any event to prepare the concentrate, and by doing it at this point it is possible to use hydrogen sulfide that contains inert gases and would otherwise have to be flared. The hydrogen sulfide also has the property of flocculating any fine ore solids which may come over with the liquor, and also reduces the probability of precipitation of troublesome ferric hydroxide in the neutralization operation.

The neutralization operation is carried out in a series of four agitated tanks. Coral slurry is metered in by means of variable-speed diaphragm pumps, and control is by means of pH overflowing the fourth tank. Actually, the liquor rate is the controlled variable. The neutralization vessels are covered wooden tanks, each with about 5 min nominal retention at design rate. A draft fan draws the carbon dioxide generated by the neutralization reaction off to a stack. Agitation is by standard turbine-type units designed for an input of 1.0 hp per 1000 gal in each tank.

The neutralization reaction precipitates gypsum equivalent to the acid destroyed. Filtration and separate disposal of this material was originally planned; however, there are obvious advantages in simply returning this material as a thickner sludge to the CCD system handling the leached slurry.

c) Sulfide precipitation

Analysis of the neutralized liquor, which constitutes the feed to the sulfide precipitation step, is shown as Table IV. The flowsheet for sulfide precipitation is shown as Fig. 5.

The neutralized liquor is pumped to the leaching section, where it is preheated to about 170°F by direct contact with the atmospheric steam off the leaching flash tanks. It is then picked up and pumped to the heaters of the sulfide system proper. Here, direct contact with 15 psig steam heats the liquor to 245°F, and the hot liquor is pumped into the precipitation vessels. These vessels are horizontal cylindrical units, lined with acid-proof brick, and divided internally into three compartments by brick baffle walls. Each compartment is fitted with an agitator; these are turbine-type units each with two impellers, and are designed to draw 55 hp (about 10 hp per 1000 gal). Gaseous, high-purity hydrogen sulfide is injected to maintain a total pressure of 150 psi. Under these conditions, over 99 pct of the Ni and 98 pct of the Co is precipitated as the sulfide. The precipitated slurry is blown down directly into flash tanks, where the excess hydrogen sulfide separates. This gas is cooled and dried by washing with water, and is recycled by compression to the reaction vessels. There are four complete trains in the system (heater, pump reaction vessel, and flash tank). Design calls for three trains to handle full plant flow (2800 gpm). The spare train is included because the system generates scale, and downtime for cleaning is necessary.

The flashed liquid carrying the suspended sulfide product flows to two 60-ft thickeners operating in parallel by gravity. Here the solids separate. The thickened sulfide is washed in two stages using the hot water off the hydrogen sulfide cooler. This contains 30 to 40 ppm of dissolved H_2S, which inhibits oxidation of the sulfide during the washing operation. The washed sulfide, as a slurry containing about 65 pct solids, is transferred to storage in the port area using cement-mixer trucks for hauling. A battery of wooden tanks, nominally 20-ft diam by 20-ft high, are used for storage. The 16 tanks in the battery have a total capacity equivalent to about 27 days operation at design rate. In the storage tanks the slurry is permitted to settle. When the transfer from shore storage to ship is to be made, the slurry is resuspended by means of a specially-designed agitator which can be moved from tank to tank.

The chemistry of the precipitation operation deserves some further discussion. The original scheme for precipitating nickel and cobalt as sulfides from acid media called for a *catalyzed reaction;* nickel or iron powder was recommended as a suitable catalyst.[8] Further investigation showed that by increasing the temperature and hydrogen sulfide pressure, the precipitation would take place without a catalyst. Under these more severe conditions, a part of the metals precipitated almost instantaneously;

Table IV. Sulfide Precipitation System. Typical Analyses of Process Streams and Distribution of Metals in Products

Component	Feed Liquor, Gpl	Stripped Liquor, Gpl	Cone, Pct	Recovery in Cone, Pct
Ni	4.15	0.037	55.10	99.0
Co	0.45	0.007	5.87	98.1
Fe	0.56	0.47	0.30	4.0
Al	1.61	1.42	0.02	0.1
Mn	1.38	1.22	—	0.00
Mg	1.93	1.71	—	0.00
Cr	0.21	0.16	0.37	13.1
Cu	0.08	—	1.02	100.0
Zn	0.13	—	1.68	100.0
Pb	—	—	0.003	100.0
Ca	0.10	0.09	—	0.00
S (as sulphide)	—	—	35.60	—
SO_4	27.2	24.1	0.04	—
Free acid	—	7.0	—	—
pH	2.4	—	—	—

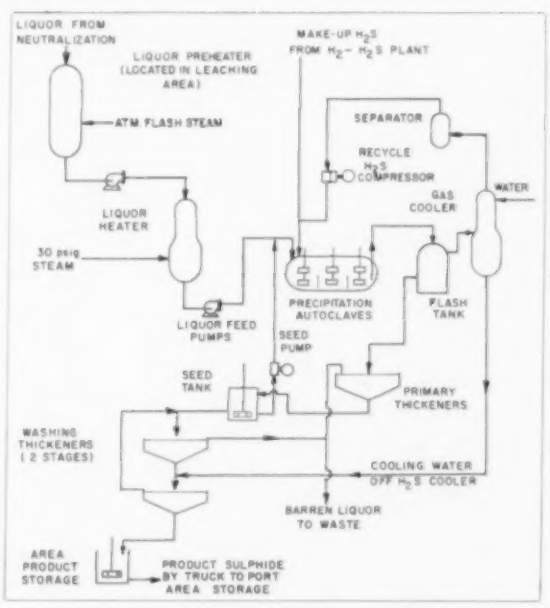

Fig. 5—Sulfide concentrate precipitation system.

and the balance precipitated at a relatively slow rate. The reaction involved is

$$NiSO_4 + H_2S \rightarrow NiS + H_2SO_4$$

Thus, as the reaction proceeds, the concentration of nickel in solution decreases, and the acid concentration increases. Both these effects work toward reducing both rate and ultimate precipitation. At some point in the course of the reaction, the nickel level gets sufficiently low, or the acid level sufficiently high, to stop the reaction. The concentration range through which the precipitation proceeds spontaneously is called the *self-nucleating* region. Beyond these conditions, the reaction takes place on existing solid surfaces, and is probably truly catalytic.

To use this catalytic effect to attain a higher overall precipitation, the liquor is *seeded* with previously prepared precipitate. This improves both recovery and reaction rate. There is another important effect; it provides a control over the particle size of the product. The seed recycle adopted as *standard* is 200 pct of the weight of new precipitate formed.

Detailed analysis of the pilot plant operation led to the conclusion that temperature and hydrogen sulfide pressure are the two most important variables. Of lesser importance are such variables as the initial metal concentration, initial pH, amount of seed, and so on. The combinations of temperature and pressure that give an average precipitation of 99 pct Ni and 98 pct Co are shown in Fig. 6.

Typical analyses of the sulfide product and the stripped liquor are shown in Table IV. The interesting feature of these figures is the fact that manganese and calcium, both of which constitute nuisances in the refinery, are totally rejected to waste.

The hot sulfide feed liquor poses a difficult corrosion problem. Of the readily-available structural metals, only Hastelloy alloy C and titanium remain unaffected in it. All wetted metal parts, starting with the liquor heaters are, therefore, made of Hastelloy C. Where slurry of liquor is cool enough, a limited amount of rubber-lined pipe and equipment is used.

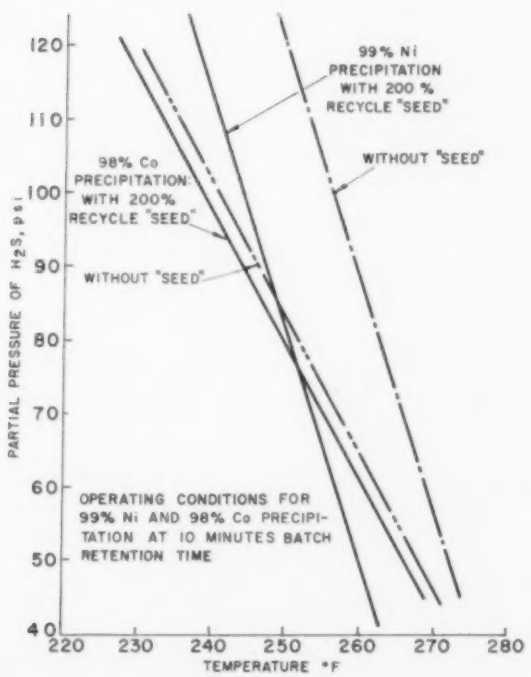

Fig. 6—Precipitation of nickel and cobalt sulfides.

Auxiliary facilities

The sulfide precipitation system requires the unit for generating hydrogen sulfide as a satellite plant. This plant, a dual unit with a nominal capacity of 60 tons of H_2S per day, is the largest in the world. Hydrogen sulfide is generated by direct reaction of hydrogen with sulfur at 850° to 900°F. This reaction is exothermic and as such is self-supporting without addition of supplemental heat. The hydrogen sulfide is scrubbed with molten sulfur at about 300°F to strip out unreacted sulfur vapor before cooling and liquefaction. Conversion of hydrogen is 97 to 98 pct. The hydrogen required is prepared by reforming liquefied petroleum gas (propane or butane) with steam in a more-or-less standard unit.

Another auxiliary facility essential to operations is the sulfuric acid plant. This consists of two 650 tpd contact units, and is one of the larger acid plants in the world. It operates on the standard grade of dark sulfur, and, in addition, uses the high-carbon *blowdown* from the hydrogen sulfide plant. At capacity operation, it consumes 371 gross tons of sulfur per day. It also generates high-pressure steam in its waste-heat boilers. In balanced operation, over 50 pct of the high-pressure (650 psig) steam used for agitation and heating in the leaching system is generated in the acid plant.

The handling and storage of materials required a major installation. Harbor facilities for ocean going vessels were required, and means of storing liquid fuels and sulfur in shipload lots were necessary. A channel and turning basin were dregged, and dock facilities provided to handle vessels of 10,000 tons.

The vessel for transporting the sulfide concentrate is a Liberty ship especially modified for the Moa Bay-US run. In addition to the sulfide slurry tanks, of which there are eight of 5100 cu ft capacity each (220 tons concentrate at 65 pct solids), the ship is fitted with four liquid sulfur tanks and four LPG tanks.

Sulfide concentrate is now being transported by this ship to Port Nickel, La., where Freeport Nickel Co. has constructed a refinery especially designed to treat the Moa Bay concentrates. Information on the operation of this refinery is beyond the scope of this article, but it will be the subject of a future article which will complete the story of Freeport's nickel leaching and refining operations, based on the lateritic nickel ores of Moa Bay, Cuba.

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TREATMENT OF NICKEL-COPPER MATTE

In the treatment of copper-nickel sulfide ores, separation of copper from the nickel has been one of the major metallurgical problems. This article describes techniques adopted by Inco on the basis of its laboratory studies and pilot-plant development.

by Kelvin Sproule, G. A. Harcourt, and L. S. Renzoni

FOR over 50 years, the nickel-copper-iron sulfide ores of the Sudbury district in Canada have been the world's principal nickel source. Separation of copper from the nickel has been one of the major metallurgical problems in treatment of these ores. Classically, the bulk of the copper was removed by the Orford process. But much improved separation was achieved by International Nickel's successful development of a process based on flotation and magnetic separation of slowly-cooled bessemer matte to yield nickel sulfide, copper sulfide, and a metallic fraction containing the precious metals.[5] This process, marking the first commercial application of mineral dressing principles to matte products, was established on a commercial scale at Copper Cliff in 1944, and by late 1948 all Inco matte was so treated. Since the nickel sulfide was low in both copper and precious metals, it became possible to sinter part of it for direct production and sale of nickel oxide sinter, without the previously required refining operations. Since 1956, another portion of the nickel sulfide has been used in production of matte anodes for direct electrorefining of nickel and recovery of elemental sulfur.

Since the last general reviews of Inco metallurgy,[1, 2] major changes have been reported in the literature. In 1952, coal-fired reverberatory furnace smelting of copper flotation concentrate was replaced by oxygen flash smelting, in which sulfur was recovered as liquid sulfur dioxide.[3] In 1956, a low-nickel pyrrhotite concentrate was separated by flotation and magnetic separation for production of high-grade iron ore.[4] The sulfides remaining after removal of the copper and iron concentrates are recovered as a nickel-copper concentrate which, after multi-hearth roasting, is smelted and oxidized to produce *bessemer* or *converter* matte containing 46 pct Ni, 30 pct Cu, and 21.5 pct S. As mentioned, the Orford process[5] was the principal method for bulk separation of copper sulfide from nickel sulfide during the first half of this century. The matte, smelted in two stages with sodium sulfide, yielded a sodium-copper sulfide *top* and a nickel sulfide *bottom*, as immiscible liquid layers. The nickel sulfide bottoms were further refined, either electrolytically or by the Mond atmospheric pressure carbonyl process.

Other nickel producers employ a variety of processes for copper-nickel separation. For example, Falconbridge extracts a large part of the copper in converter matte by roasting and sulfuric-acid leaching before electrolytic refining of the nickel. Sherritt Gordon uses pressure ammonia leaching on a low-copper, high-nickel sulfide ore concentrate. B.A.S.F. in Germany employs a modification of the Mond process based on nickel extraction at 200 atm from matte containing only sufficient sulfur to finally combine with the copper as Cu_2S. Soviet nickel production is derived largely from smelting of nickel-copper sulfide ores, and it is believed Inco's matte flotation process has been adopted on a large scale in the USSR.[10] The lateritic nickel ores of Cuba, New Caledonia, and Oregon contain no copper.

KELVIN SPROULE is with the International Nickel Co., while G. A. HARCOURT and L. S. RENZONI are with the International Nickel Co. of Canada. This paper was a part of the International Symposium on the Extractive Metallurgy of Copper, Nickel, and Cobalt of the 1960 AIME Annual Meeting.

Constitution of bessemer matte

Nickel and copper in bessemer matte occur mainly as Ni_3S_2 and Cu_2S. The matte is often about 10 pct deficient in sulfur for these sulfides, and the excess metal occurs in the matte as a nickel-copper alloy. Hayward,[11] in 1915, and Stansfield and Faith,[12] in 1924, developed Ni_3S_2—Cu_2S phase diagrams, and the latter showed that the nickel and copper sulfides in the solid matte are relatively pure. In 1940, Koster and Mulfinger[13] refined the diagram and extended it to other parts of the Ni-Cu-S system. The Cu_2S-Ni_3S_2 diagram shown in Fig. 1, and a projection, Fig. 2, showing the ternary eutectic and ternary eutectoid planes and traces of the valleys leading to the eutectic and eutectoid points, "E" and "T", were produced by F. N. Rhines and co-workers.[14] While generally supporting Koster and Mulfinger, Rhines relocated the ternary eutectic (from 13.3 pct Cu to 10 pct Cu) and the ternary eutectoid (from 2 pct Cu to 5.5 pct Cu).

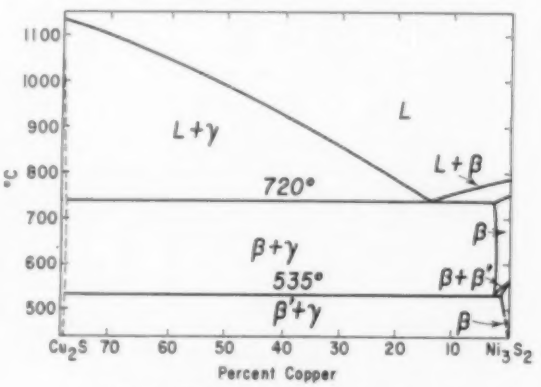


Fig. 1—The Cu_2S-Ni_3S_2 phase diagram.

Briefly, it is seen that Cu_2S and Ni_3S_2 are miscible in all proportions in the liquid state, and that they are almost completely immiscible at room temperature. While it could be deduced that a mechanical separation of copper and nickel sulfides is theoretically possible, the grain size of matte cast in the normal manner is prohibitively fine, and since most commercial mattes are rather close to the eutectic position, this might have been expected even with slow cooling. However, as shown below, diffusion is so rapid that upon slow cooling over an extended yet practical period of time and through the appropriate temperature range there is a high degree of divorcement of the eutectic and the eutectoid into relatively coarse copper sulfide, metallics, and nickel sulfide.

The compound Ni_3S_2 is allotropic. The high-temperature beta form transforms to the beta prime form at 990°F (532°C). In the presence of copper and with a sulfur deficiency, as in commercial mattes, the ternary eutectoid is at about 520°C. From Fig. 2, it is seen that beta Ni_3S_2 can dissolve up to 6 or 7 pct Cu_2S, and that the solubility of Cu_2S in beta prime Ni_3S_2 is much lower.

Fig. 3 shows the microstructure of a 25 pct Cu, 52 pct Ni matte slowly cooled from the liquid at 0.10°F per min to the ternary eutectic temperature, 1070°F (575°C), and held briefly before quenching. The coarse proeutectic Cu_2S dendrites and the one proeutectic metal grain, shown in Fig. 3, formed as the matte slowly cooled. The darker portion of the matrix is eutectic structure formed in quenching. The lighter, unresolved portion of the background represents divorced eutectic which had solidified slowly before quenching and from which the Cu_2S and metal had diffused to deposit upon coarse grains already present, leaving beta Ni_3S_2. Upon quenching, this beta Ni_3S_2 transformed into a fine eutectoid of beta prime Ni_3S_2, Cu_2S, and metal which is unresolved in Fig. 3, but is resolved at X1000 in Fig. 4.

When slow cooling is extended through the eutectoid temperature of about 968°F (520°C), the eutectoid copper sulfide and metal do not nucleate, but instead divorce (as in the case of the eutectic), leaving the nickel-sulfide matrix free from other visible constituents. Further slow cooling to room temperature permits the copper content of this nickel sulfide to drop by diffusion from about 2 pct to 0.5 pct or possibly less. Fig. 5 shows matte slowly cooled to room temperature.

It is well known that the decreased freezing rate of a melt results in increased grain size. For Inco matte containing about 25 pct Cu and 52 pct Ni, cooled from 1600°F to 900°F at rates between 0.1°F and 60°F per min, the diameter of the copper-sulfide grains varies approximately as the cube root of the cooling time. This applies to both the proeutectic and eutectic grains.

A marked segregation of copper sulfide occurs in both laboratory and commercial ingots. Thus, a 25 pct Cu matte may contain 35 pct Cu near the top and sides, and as little as 11 pct Cu in the center-bottom part, shown in Fig. 6. Proeutectic Cu_2S would first precipitate in the coolest regions of the solidifying matte, normally near the top and sides, and no matter where formed, it would tend to rise in the molten matte when there is an appreciable sulfur deficiency. Grains of Cu_2S located near the cooler surfaces of the melt tend to grow with their major axes perpendicular to the surface. Proeutectic metallic flakes tend to sink in the *mother liquid* and are found concentrated toward the bottom of the mass.

Precious metals: Bessemer matte normally has insufficient sulfur to form Cu_2S and Ni_3S_2, and a metallic phase separates in the three stages already

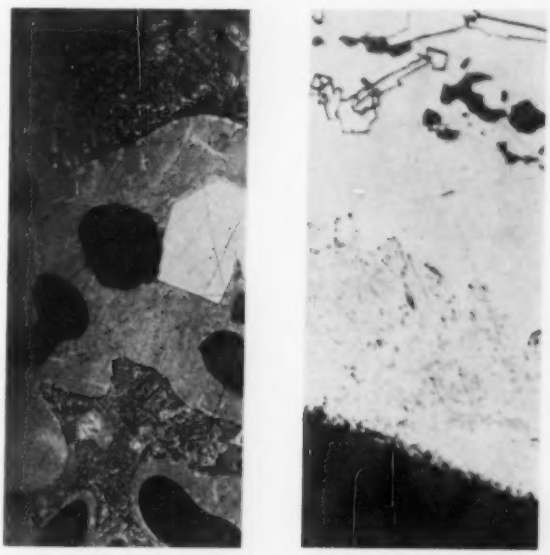


Fig. 3—(Left) Matte quenched from eutectic temperature, showing coarse proeutectic CuS (dark grey) and metal (white), eutectic (mottled), and eutectoid (light grey), X40. Fig. 4—(Right) Same as Fig. 3 but at X1000 with eutectic at top and eutectoid adjacent to Cu_2S grain.

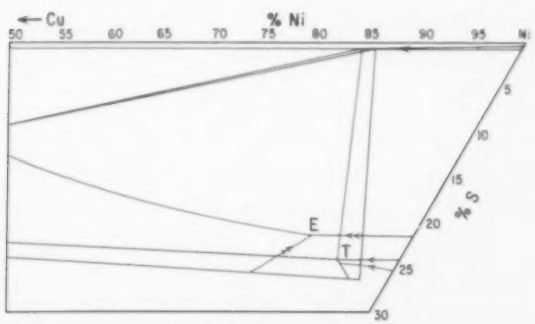


Fig. 2—A portion of the Ni-Cu-S phase diagram, indicating eutectic and eutectoid planes, and traces of valleys leading to eutectic and eutectoid points.

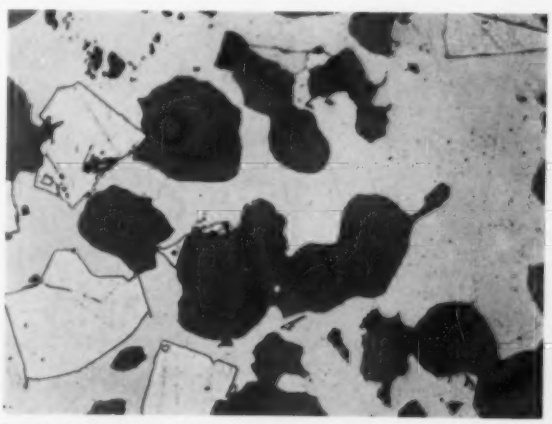


Fig. 5—Matte fully cooled at slow rate, X200. Shown are Cu_2S and metal grains in a nickel sulfide matrix.

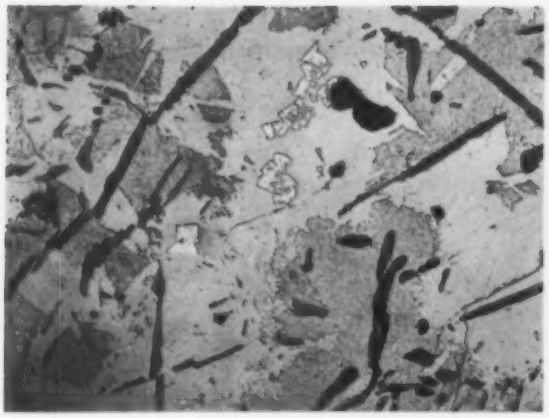


Fig. 6—Bottom portion of large ingot, depleted in Cu_2S, X40.

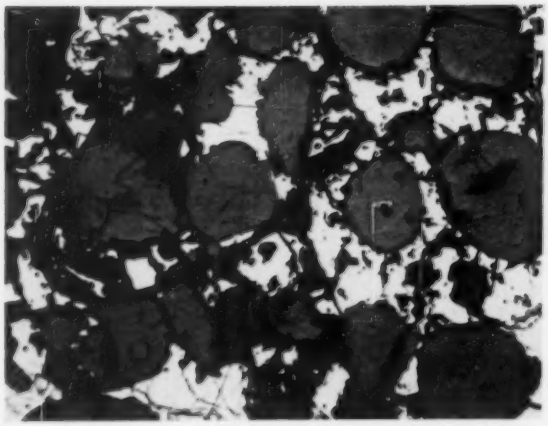


Fig. 7—Intergranular fracturing in matte in process of being crushed, X100.

discussed: proeutectic, eutectic, and eutectoid. In slowly cooled normal mattes, the metallics contain about 20 pct Cu, independent of appreciable variations in matte composition. The amount of metallics present of course depends on the sulfur deficiency of the matte as controlled by the converter finishing procedure. The ratio of concentration of the platinum metals and gold in the metallic grains of the slowly-cooled matte is about 100 to 1. Silver, on the other hand, is strongly concentrated in the copper sulfide, not surprising in view of the greater affinity of sulfur for silver than for platinum metals and gold, and the isomorphism of Ag_2S with Cu_2S.

Matte separation

Interest in the separation of matte constituents, especially separation of metallics from sulfides, has been shown by several investigators. Skappel[7] in 1925 proposed treating many materials, including iron mattes containing about 5 pct each of nickel and copper, by fusing or sintering, generally with, but also without, the addition of *splitting-up agents* which permitted reducing the mass to a powder prior to separating the constituents by mechanical or chemical means, including sizing and magnetic separation. Powell and Deering[9] in 1929 proposed a similar procedure employing disintegrating agents to recover platinum metals from sulfur-deficient nickel-copper-iron matte by separation of the precious-metal-bearing metallics from the sulfide. H. and L. Schlecht[8] proposed a modification of this method, without a disintegrating agent, for the separation of copper-nickel matte into high-sulfur and low-sulfur (metallic) fractions, but no major separation of copper from nickel was obtained. Koster and Mulfinger[10] suggested that a metallic nickel fraction might be separated from nickel-copper matte.

Inco had occasionally examined the mechanical separation of matte constituents in earlier years, and a resumption of such work led to commercially-attractive results. Small crucibles of bessemer matte were cooled from 1800°F over periods of about a week, and satisfactory structures were obtained without difficulty. In successful laboratory flotation tests, pentasol amyl xanthate and pine oil were used to float the copper sulfide from the finely-ground matte, after magnetic separation. High alkalinity was maintained with lime. Diphenylguanidine soon proved to be more selective for the separation of these sulfides.[15] The weaker dithiophosphates also yield good results. More collector is required than when treating ore, due to the greater proportion of floatable material in the matte and the finer grind.

High-grade copper and nickel concentrate were obtained by rougher flotation at a relatively coarse grind of 30 to 50 pct + 325 mesh, and refloating the rougher concentrate after regrinding to about 5 pct + 325 mesh. Cleaner tailing was recycled to heads. In this way, bessemer matte containing 25 pct Cu and 52 pct Ni ordinarily yielded a copper concentrate of 73 pct Cu and 5 pct Ni, and a nickel concentrate of 2 pct Cu and 70 pct Ni, while producing no middling apart from the magnetic concentrate. By regrinding and refloating the nickel concentrate, the copper content was decreased to 0.5 pct in the purest fractions, but the best copper concentrate contained about 3 pct Ni. The magnetic concentrate, without retreatment, was about 20 pct of the matte.

An important characteristic of slowly-cooled matte is its tendency to fracture between the copper and nickel sulfide grains rather than through the grains (Fig. 7). This feature is of great practical value in effecting separation. Sulfur addition to laboratory melts decreased the tendency toward intergranular fracture.

Other mattes: After success with nickel-copper matte, it was apparent that similar procedures might be applicable to separation of other metals. Separations obtained at once on cobalt-copper matte were only moderately less sharp than with nickel-copper. A good separation was obtained on a 70 pct copper sulfide-30 pct zinc sulfide matte, slowly cooled over the 2200°F to 2000°F freezing range and below, and an 85 pct lead sulfide-15 pct zinc sulfide matte gave promise.

Pilot-plant developments

Pilot-plant flotation commenced in 1943 at a treatment rate of 3 tpd. Matte was supplied in individual 5 to 25 ton lots which had been cooled 3 to 15 days in cast iron, brick, or tamped graphite molds. In the final flowsheet, the crushed matte was ground in a 30x36 in. rod mill in closed circuit with a 12-in. spiral classifier. Magnetics were removed by a belt magnetic separator. Classifier undersize was floated in five 1-cu ft cells to yield as tailing a final nickel concentrate, and a rougher copper concentrate, which was reground and cleaned in three stages. In one of the best sustained runs, a matte containing 22.7 pct Cu, 55.1 pct Ni, 1.0 pct Fe, and 21.2 pct S, cooled for 11 days, yielded the products

Fig. 8—Matte casting and cooling operations.

shown in Table I, in addition to 20 pct magnetics. Reagents were 0.5 lb per ton diphenylguanidine added to the mill, 0.05 lb per ton pine oil, and lime to pH 12.4.

Nickel in the copper concentrate was mainly in the form of mixed grains, while copper in the nickel concentrate was, apart from the coarse portion of cleaner tailing, due to unfloated fines. An excellent separation between the copper and nickel sulfides was obtained even on the −10-μ material.

Based on the results of the 3-ton pilot plant, a 100-tpd plant was put into operation in September 1944, using basically the same flowsheet. Satisfactory separation of copper sulfide, nickel sulfide, and metallics was obtained without metallurgical difficulties, and construction of a 1000-tpd plant using the same basic procedures was started early in 1945. After construction had commenced, it appeared that completion would be delayed by steel shortages; therefore, in late 1946 the 100-ton plant was enlarged to 300 tpd. In addition to serving as a commercial-scale pilot plant to provide data for the full-scale design, this plant produced 240 million lb nickel in sulfide, some of which was used for development of a new product, Nickel Oxide Sinter. The 300-ton plant remained in operation until September 1948, when the full-scale 1000-ton plant was treating the entire output.

Table I. Results of Matte Separation on 3-tpd Pilot Plant

	Nickel Concentrates* (97 Pct Ni Recovery)						Copper Conc* (95 Pct Cu Recovery)		
	Rougher Tailing			Cleaner Tailing					
Pct Total Matte	58			12			30		
Mesh Size	Pct Wt	Pct Cu	Pct Ni	Pct Wt	Pct Cu	Pct Ni	Pct Wt	Pct Cu	Pct Ni
+400	34	0.9	69.9	12	5.5	70.2	15	72.9	5.6
−400 + 800	29	0.8	70.4	29	2.3	70.8	42	73.0	5.0
−800 + 1600	17	1.0	70.4	23	2.6	68.8	25	74.2	3.7
−1600 (10 μ)	20	2.5	67.5	36	8.6	58.8	18	74.2	2.8
	100	1.2	69.7	100	5.0	66.0	100	73.5	4.4

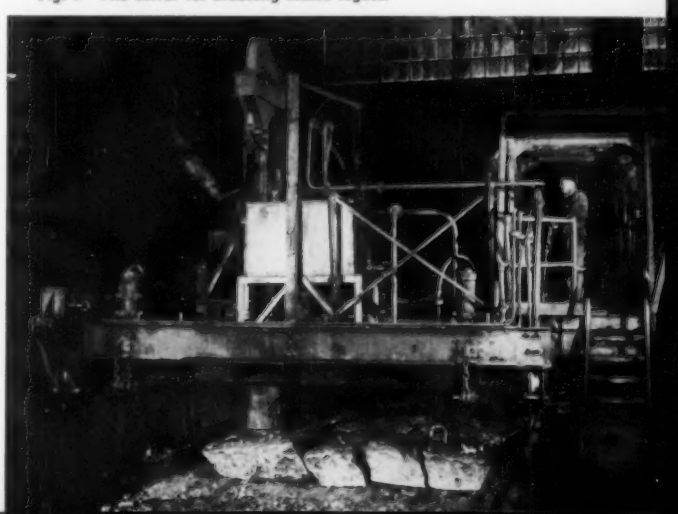
* In addition, the matte yielded 20 pct by wt of magnetic concentrate, which upon regrinding could be decreased to 10 pct.

Current practice

Converters: Little change in converter practice was required to produce a bessemer matte suitable for matte separation. For this purpose the matte should have a minimum iron content consistent with retention of cobalt, and sufficient sulfur to avoid more than 10 pct metallics in the solid matte. A low finishing temperature helps retain sulfur. Finished matte is transferred to a cooling converter, given a short final blow, held quiescent to permit separation of fine magnetite and slag, and cast at about 1800°F.

Casting and Slow Cooling: Matte casting, cooling, and related operations are conducted in a building (Fig. 8) which houses 220 molds, a storage and cooling area, a matte breaker, and crushing equipment. The requirements of optimum grain size in the solid matte and reasonably easy removal and breakage of the ingot were met by a 25-ton ingot

Fig. 9—Pile driver for breaking matte ingots.



cast in a rectangular mold, 12.5x8x2 ft, with 45° sides. Initially, cast-iron molds were considered satisfactory, but they failed from distortion and cracking after about 200 fillings. Subsequently, brick molds were standard, and now further work has led to the use of castable fireclay molds, which in the past two years have yielded 700 fillings with only minor patching. They require a lime wash before filling.

The molds are set into the ground to promote slow cooling. The matte is cast at about 1800°F. Some matte chills against the mold wall, but heat in the ingot anneals this skin and results in a satisfactory grain size. Occasionally, a mold will lift with an ingot, if the mold is distorted or the ingot not fully cooled. However, this can be avoided by proper maintenance and by adherence to the casting schedule. The ingots are lifted from the mold by refractory-coated steel lugs suspended on the side of the mold before the matte is poured. Immediately after the molds have been filled, insulated steel covers are placed over them. The covers are removed three days later, and the ingots allowed to cool for another day to about 400°F. At this temperature, shrinkage of the matte is sufficient to help avoid sticking in the molds. After lifting, ingots are stacked for storage, then transferred by tongs for breaking by a 10-ton pile driver equipped with a cross-chisel bit, Fig. 9. The matte is then pushed by a bulldozer blade (on a carriage with the pile driver) into a 48x66 in. jaw crusher which reduces it to about 7 in. The crushed matte is conveyed to two crushers in series where it is progressively reduced to about ¼ in. A baghouse collects dust from crushing and conveying.

Milling and Flotation: The constituents of the bessemer matte are separated by ore dressing methods, Fig. 10. Since the materials are of high value, special precautions are taken against losses. Baghouses collect dust at conveyor transfer points and bin feeders; no outlet to sewer is permitted, each section of the plant being surrounded by a 2-ft curb to contain any spillage; and all water leaving the building is clarified.

The ¼ in. matte is fed by weightometer to a 6x10 ft rod mill and then to a 6x10 ft ball mill in closed circuit with a belt magnetic separator and a rake classifier. Magnetics are re-treated as described later, and classifer overflow at 25 pct + 325 mesh is pumped to flotation cells (mechanical type) on the upper floor of the building. A pH of 12.4 is held by addition of dry hydrated lime to the mills. Diphenylguanidine, added to the grinding circuit, acts as collector and frother. Particles containing copper are floated in the first step, leaving a high-grade nickel concentrate containing less than 1 pct Cu. The rougher copper concentrate, containing mixed grains, is thickened and reground to 7 pct + 325 mesh in a 6x10 ft ball mill in closed circuit with a continuous centrifugal classifier, and then pumped to the three-stage pneumatic-cell flotation cleaning circuit. First cleaner tailing is a nickel concentrate containing about 10 pct Cu used for blending with part of the rougher tailing to produce a nickel product containing 2.5 pct Cu. The third cleaner concentrate is the final copper concentrate.

The final products from flotation are thickened separately and pumped to agitate storage tanks. Because of the tendency for rapid settling of the sulfides, a flow-type pressure device was developed to record and control thickener loads by regulating the withdrawal of underflow. This also yields an underflow of constant pulp density.

Metallics recovery: The precious metal-bearing metallic constituent, of about 80:20 nickel to copper ratio, must be removed to permit production of relatively pure nickel and copper sulfides. This is accomplished by multiple magnetic separations. The coarser metallics are present as flakes, and are difficult to pump as a slurry. Since they become larger upon grinding, the first stage of magnetic separation is in the primary grinding circuit.

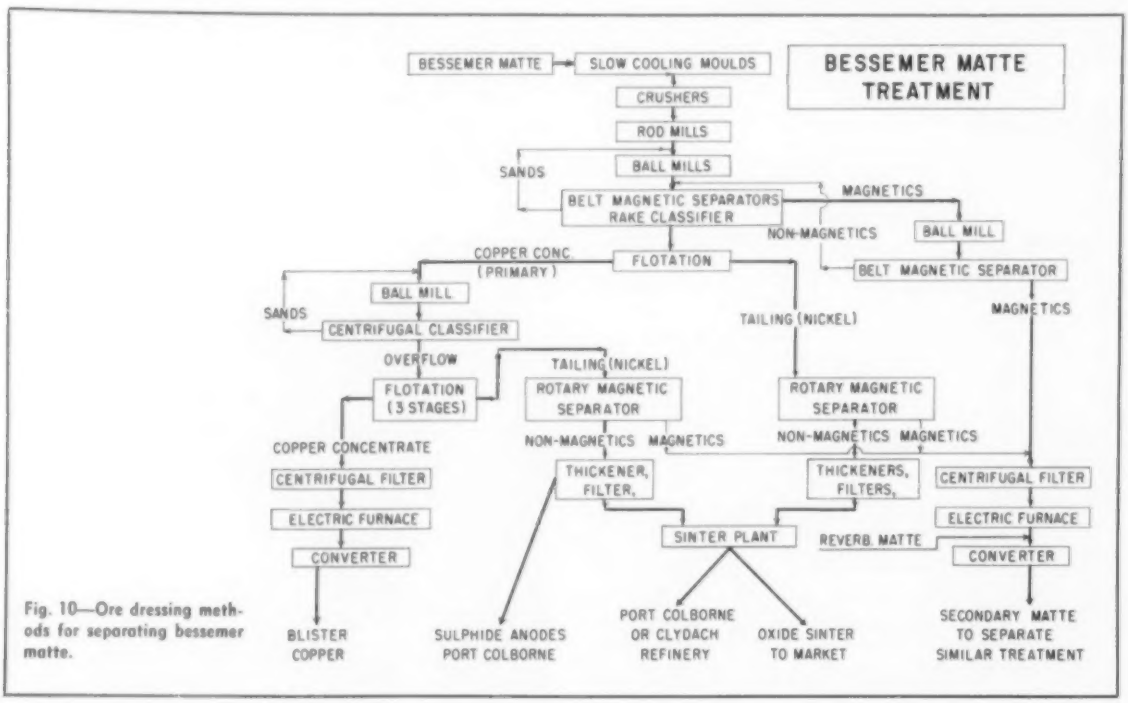


Fig. 10—Ore dressing methods for separating bessemer matte.

At this stage the metallics have sulfides attached. These are freed in a metallics regrind circuit, consisting of a 6 x 10 ft ball mill and a belt magnetic separator. Non-magnetics return to the primary circuit, and the magnetics are filtered by basket centrifuge for smelting, as described later.

Fine metallics not removed by the belt magnetic separators are later recovered by high-intensity magnetic separation. For this purpose Inco developed a high-intensity rotary magnetic separator.[15] The separator embodies 10 poles of T-shaped cross section—the bottom of the T being fastened to a hub, the cross of the T forming a part of the outer surface of the cylindrical body. Circumferential V-grooves provide ridges of maximum magnetic flux. With the pulp cascading down the rising surface of the cylinder, direct contact is made between the pulp and the pole faces to remove even fine magnetic particles. Heat from the electromagnets is dissipated efficiently through direct contact with the slurry.

Magnetics are released from the pole pieces by interrupting the power on each pole at its highest position, aided by a high-pressure water spray and the use of a rubber scraper serrated to match the grooved face of the pole pieces. Power is again applied to each pole as it reaches its lowest position, where a serrated water-flushed divider separates the flow of magnetic and non-magnetic particles. These separators are 36 in. in diam and 18 or 36 in. wide.

Product treatment

Copper sulfide concentrate: Copper concentrate, containing about 73 pct Cu and 5 pct Ni, is centrifuged to 4 pct moisture and smelted in a 6000-kva, three electrode in-line electric furnace. The resulting matte is bessemerized to blister copper.

Metallics: To recover the copper and nickel from the metallics and to further concentrate the precious metals, this product is resulfurized by melting in a 3000 kw arc furnace, and charging into a converter with reverberatory matte. The product is a secondary matte, which is processed similarly to primary matte. Nickel sulfide produced from secondary matte is refined by the sulfide anode process at Port Colborne. The secondary metallics are also refined at Port Colborne.

Nickel sulfide concentrate: There are several outlets for the nickel sulfide product, but the bulk of it is refined to high-purity metal. A portion of the rougher tailing containing over 71 pct Ni and less than 1 pct Cu is sintered to oxide for sale to the steel industry. Another portion of the nickel sulfide is refined by the new matte-anode process described below, and the rest is sintered for refining by the Mond carbonyl or conventional electrolytic processes.

Electrolytic refining of matte anodes

Before 1956, all nickel sulfide intended for electrolytic refining was sintered to oxide, reduction smelted, and cast into metal anodes. Sintering of fine nickel sulfide, however, is far from an ideal operation, primarily because its low melting point results in fusion of the material in preference to oxidation. For this reason, it is necessary to dilute the raw sulfide with sinter returns in the ratio of about one sulfide to five sinter to obtain the desired oxide. The sintered product is a refractory material which must be reduction smelted at a high temperature to produce metal anodes.

The matte anode process, development of which commenced in 1951, obviates these objectionable high temperature steps and provides a shorter route towards the production of high-purity nickel and associated products. The portion of the fine nickel sulfide treated by this process is remelted at about 1800°F and cast directly into matte anodes for electrorefining. The contained sulfur and selenium is recovered in elemental form, in addition to the usual byproduct elements.

In the processing of sulfide nickel ores containing minor amounts of copper, such as Inco's Thompson ores, the bessemer matte requires no prior copper separation, and matte anodes can be cast directly from the bessemer converters. The new Thompson plant, scheduled for completion in 1960, will embody this system; the matte anodes will be refined on the site in an electrolytic refinery now under construction.

As previously discussed,[6] Inco matte anodes are distinguished from other sulfur-bearing nickel anodes by their high sulfur content. This, ideally, is sufficient to form Ni_3S_2, so that separation of a metallic phase is essentially avoided. However, up to about 15 pct metallics is well tolerated.

Anode production, refining, and sludge treatment: Anodes are cast in open iron molds. Tendency toward anode fracture upon air cooling below the beta-to-beta-prime transformation at about 960°F was overcome by removing the anodes from molds at 1000°F and slowly cooling them to about 300°F. Air cooling is satisfactory after this point.

The high cathode purity commercially obtained from metal anodes has been maintained in the sulfide anode operation. Electrolyte purification for the elimination of iron, copper, arsenic, and lead, and for the separation and recovery of cobalt is essentially similar to conventional practice.

Matte anodes have a distinct advantage over metal anodes in regard to the ratio of concentration of the noble metals. The elemental sulfur anode sludge containing the precious metals is washed, then melted continuously at 275°F, and filtered to remove sulfides and the precious metals. The clear sulfur filtrate, containing about 0.15 pct Se, is distilled for the production of high-purity sulfur and for recovery of a 20 pct Se fraction for further refining at Inco's copper refinery.

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APPLICATION OF MAGNETIC MATERIALS

An examination of some of the applications of magnetic materials from the standpoint of the metallurgical technology that has made these applications possible.

by Martin F. Littmann

MODERN quantum theory tells us that the ferromagnetism displayed by iron, cobalt, and nickel is associated with the uncompensated spins of electrons in the third shell surrounding the nuclei of these atoms. Suppose, for a moment, that some mysterious force would cause the number of electrons with positive and negative spins to balance each other exactly so that there would be no net magnetic moment. Even though the spins of these electrons are invisible to the eye or any instrument man has yet devised, the consequences of such a tiny change would be catastrophic.

No longer would it be possible to generate electrical power in huge quantities and transmit it great distances to perform a myriad of tasks for man in the instant of his command. Radio and telephone would no longer exist. Even our automobiles would not operate and virtually all industry would suddenly cease to function. Civilization, as we know it, and our mode of life would necessarily revert to the state before Sturgeon made the first electromagnet and Faraday and Henry made the first transformers, only one century ago.

If we were to select one criterion of magnetic materials' importance, it could very well be the production of electrical energy. Since 1900 the use of electrical energy in the US has doubled every 10 years. The rest of the world has shown nearly the same trend.

In the generation and use of electrical energy, magnetic materials play an indispensable role. Basically, magnetic materials, particularly metals and alloys, make it possible to build transformers that change voltages to permit efficient transmission of power . . . transducers that translate mechanical energy into electrical energy and vice versa . . . and modulators that can be considered as magnetic valves to control electrical energy. In addition, of course, magnets are used because of their powers of attraction and repulsion.

Fundamentals of magnetism

As the term ferromagnetism already implies, the most common and most important magnetic material is iron and its alloys. The properties of iron—or any magnetic material—are fundamentally described by hysteresis loops and magnetization curves, as illustrated in Fig. 1. The intensity of magnetization or, more commonly, the induction, B, induced in iron by a magnetic field, H, is described by the magnetization curve. When the magnetic field is reversed, the original magnetization curve is not retraced, since energy is lost in the process of domain wall motion, and the variation of B vs H with cyclic magnetization traces the hysteresis loop. Important quantities used to measure the usefulness of magnetic materials are:

a) Permeability = B/H
b) Coercive force = H_c
c) Maximum flux density = B_m
d) Residual flux density = B_r
e) Maximum energy product = (B) x (−H) max.

In addition to the energy lost in alternating current magnetization represented by hysteresis loss, i.e., the area of the hysteresis loop, energy is also lost in overcoming the eddy currents generated by the changing flux. Both effects combine to produce a total energy loss or *core loss*, which is usually measured as w per lb at 60 cycles.

The first silicon irons

The conception of the alternating current method of power distribution in 1886 created the need for a magnetic material with high magnetic saturation and low core loss. The irons available at that time were very high in core loss and, even worse, became higher in loss because of magnetic aging due to carbide precipitation.

No real improvement in core material was made until after 1900 when Barrett, Brown, and Hadfield of England published the magnetic properties of iron containing 2 to 2.5 pct Si. Gumlich in Germany was stimulated by this work, and by 1903 he had fostered commercial production of silicon-iron for magnetic purposes in his country. This was being followed in the US by 1905, and in England by 1906.

The use of silicon introduced three major advantages (plus the possibility of a fourth major advantage not to be realized until 30 years later):

1) The deoxidizing action of the silicon produced cleaner metal, which had lower hysteresis loss;

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2) The increased volume resistivity reduced eddy current losses; and
3) Stabilization of the carbon reduced the aging problem.

The first silicon irons had a core loss of about 1.3 w per lb at 0.014–in. thickness, measured at 10 kilogausses and 60 cycles. Within the first 10 years of Armco Steel Corp.'s production of silicon-iron this loss had been reduced to 0.74 w per lb, and to about 0.55 w per lb by 1930. As the core material improved, larger transformers and generators became possible, and the economic value of lower core loss was recognized by price differentials of different grades of silicon-iron with varying core loss. The value of improved magnetic material is readily apparent when one considers that over 600 billion kw-hr of electricity is consumed in the US annually, and that each voltage change from generator to consumer involves loss of power because of core loss. The value of energy lost in this manner is well over $100 million annually.

Grain-oriented sheets

Improvements in the silicon-iron alloys in the early 1930s became increasingly difficult as the limits of annealing temperature and silicon content, which causes brittleness, were reached. Had it not been for the fact that these sheets were hot-rolled in packs, it would not have been possible to produce such low core loss. Furthermore, cold rolling would not have been possible with the high silicon contents. However, it was recognized that the operating induction would have to be increased, and that this could only be done by orienting the crystals of the sheet so that their directions of easy magnetization would be parallel to the direction of rolling. Although at first he did not realize that he had attained a high degree of crystal orientation in his specimens, Goss accomplished the major breakthrough that brought about greatly improved core loss and permeability. His samples were cold rolled in two steps with an intermediate recrystallizing anneal.

There followed a period of intensive experimentation by Allegheny and Armco to reduce the process for grain-oriented silicon-iron to commercial production. Today thousands of tons are produced each month and grain-oriented silicon iron has become the giant of magnetic materials. Most of the enormous quantities of electrical power produced in this Country are generated using coal as fuel to drive steam turbines. These huge machines contain rotors and stators made of a silicon-iron alloy having high permeability at high inductions and low core loss at 60 cycles. The mechanical perfection of the sheets used must be great because of the large centrifugal and vibrational forces in such machines.

The cores of the largest modern transformers may contain as much as 50 tons of grain-oriented silicon sheet about 0.014 in. thick. The overall size and bulk of transformers has not changed much in recent years, but improvements in core material, methods of use, and design have permitted higher ratings for the same physical size.

As power approaches its destination it is transformed to lower voltages. Today every home or small group of homes in this Country is serviced by a distribution transformer with a core of the highest quality grain-oriented silicon iron available. Because these transformers are continually energized, the highest permeability and lowest core loss consistent with low cost is needed.

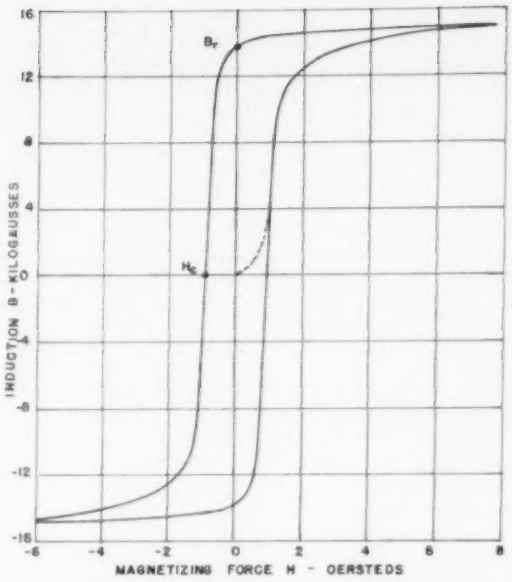


Fig. 1—Magnetization curve and hysteresis loop for commercial, annealed Magnetic Ingot Iron.

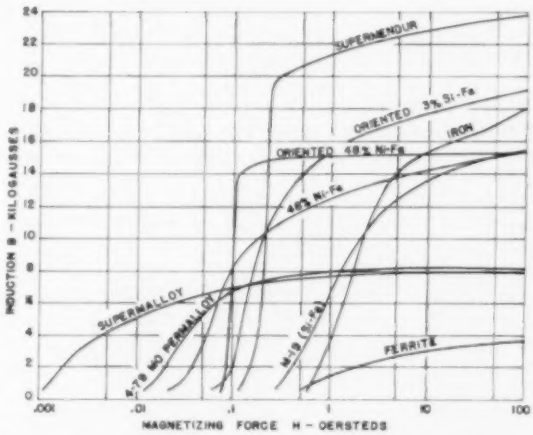


Fig. 2—Magnetization curves for important soft magnetic materials now in commercial use.

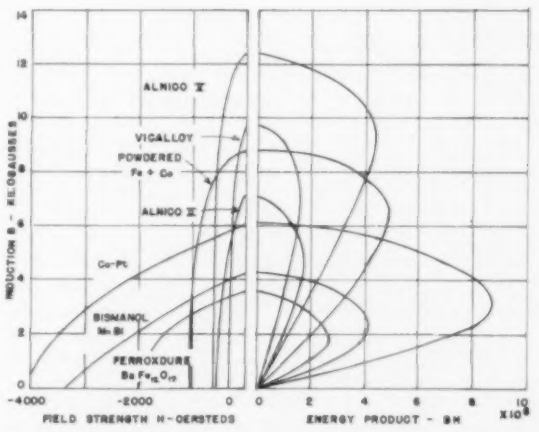


Fig. 3—Demagnetization and energy product curves for modern permanent magnet materials.

From shavers to lawnmowers, mixers to dishwashers, and washing machines to automobile generators and large motors—all use punched laminations selected from over 40 combinations of grades and thicknesses of silicon-iron alloys. These range in silicon content from less than 0.5-pct used in intermittently-operated small motors and apparatus to over 4-pct for efficient transformers and rotating apparatus. Many intricate shapes of punched laminations of silicon iron are used in watt meters, transformers, motors, and generators. Recently, even low-carbon steel has been successfully used in motors because of a favorable combination of high-induction permeability and low cost where the relatively high losses can be tolerated with intermittent use.

Iron continues to find many applications involving direct current magnetization, such as relays, armatures, pole pieces, and speaker parts.

It should be mentioned, at least, that aside from the metallurgical structure of the materials we have described, there are other factors that are extremely important considerations regarding their applicability. For alternating current applications, the strip surfaces must be treated or coated to produce sufficient insulation value to retain advantages of the thinness of the laminations in keeping eddy losses low. This is especially important in large generators and transformers to which special coatings are applied. On the other hand, for small motors a thin film of oxide is sufficient.

Modern production methods require continuous coils of magnetic materials that can be punched on high-speed presses. This means that the strip should not have an abrasive action that would cause excessive wear on the costly and intricate dies used.

Finally, the assembled magnetic structure must be free of external and internal stresses. In most cases magnetic properties of the silicon-iron alloys are almost fully developed by the producer, and an inexpensive stress relieving anneal after fabrication is sufficient to restore nearly ideal properties. In the case of the nickel-iron alloys, however, the more costly practice of high-temperature hydrogen annealing after fabrication is necessary.

Altogether, about 1 pct of the total iron and steel production in the US is used in electrical steel. Growth in the use of these electrical steels has closely paralleled the increase in use of electrical power.

Nickel-iron alloys

The telephone, the radio, television, and recording industries abound with requirements for specialized magnetic materials. Telephone receivers and loud speakers require permanent magnets with high residual induction and high coercive force. By contrast, audio transformers, filters, and magnetic shields require diametrically opposite characteristics of low coercive force and high permeability.

Nickel has been the key to alloys with high magnetic permeability at low and moderate inductions. The first practical use of nickel-iron Permalloys developed by Elmen at the Bell Laboratories was in telephone relays in the year 1921. Because of the high permeability of the 78 pct Ni-Fe, it was used very early in submarine cables as an inductive impedance to counterbalance the capacitive impedance present. The principal nickel-iron alloys now in use are 48 pct Ni-Fe and 4 pct Mo-79 pct Ni-Fe alloys. Production now is of the order of a thousand tons annually, chiefly in the form of 0.006 in. and 0.014 in. thick cold-rolled strip.

Wartime developments

The needs of our armed forces have also led to developments and applications of magnetic material. Power systems operating at 60 cycles are too heavy and bulky for aircraft. To produce the many 400-cycle power generators and transformers, material much thinner than had been previously available was required in order to reduce eddy current losses. In World War II, silicon-iron was rolled to thicknesses between 1 and 5 mils. Processes were developed to produce favorable crystal orientation for high permeability at high inductions and low losses, as well as for obtaining insulative surface coatings to prevent eddy current losses. Material 4 to 5 mils thick is used primarily for 400-cycle power transformers.

The urgency to improve radar systems led to the remarkable feat of cold-rolling coils of silicon-iron 30 in. wide to 3 mils on large rolling mills designed for strip several times this thickness. During the later stages of the war hundreds of thousands of pounds of grain-oriented silicon iron was cold rolled to 1 and 2 mils on Sendzimer mill to make the *type C* pulse transformers for radar equipment on ships and planes. These transformers made microwave radar possible and brought about accurate night bombing, which was much safer for pilot and plane.

Magnetic amplifier

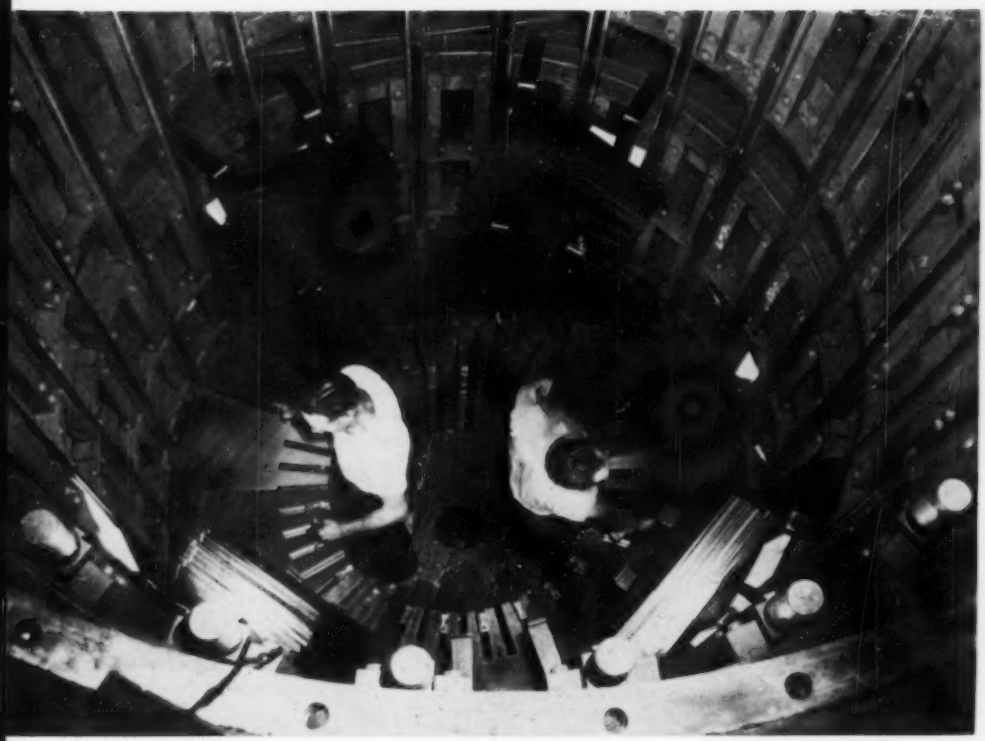
Even though the magnetic amplifier was one of the very early applications of magnetic materials, its full development and general application was not made possible until after World War II when knowledge of the German Permenorm 5000 Z came to light. This grain-oriented 48 pct Ni-Fe alloy 0.002-in. thick was developed for use in mechanical rectifiers and magnetic amplifiers. The US Navy reported that extremely reliable fire control on the German cruiser Prinz Eugen had been achieved by use of this material. It is characterized by a very rectangular hysteresis loop and low coercive force.

The extreme reliability of the magnetic amplifier for industrial and military applications of switching, logic, and control, coupled with developments in the field of transistors, is making possible a new era in control and automation. Many types of cores are made of the 48 pct Ni-Fe and 4 pct Mo-79 pct Ni-Fe tapes, 0.001 to 0.006 in. thick.

A new development is the use of magnetic amplifiers containing cores of precisely controlled characteristics as packaged reactors for standardized elements in control applications.

Ferrites and new materials

Another post-war development has been the development of a series of non-metallic substances known as the ferrites, based largely on the work of J. L. Snoek. These are refractory oxides, the most important of which are the nickel, manganese, and zinc with crystal structures similar to the familiar magnetic iron oxide. These oxide powders are pressed and fired at high temperatures to form hard, brittle



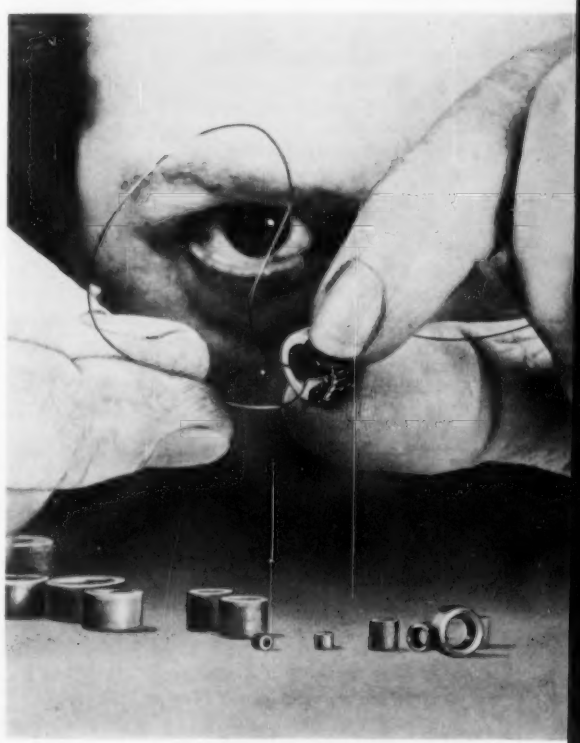
FROM THE LARGEST TO THE SMALLEST . . . Above, stacking silicon-iron laminations for the stator of a large turbine generator . . . Below, tiny tape-wound cores of Ultrathin 4-79 Mo-Permalloy used in digital computers.

bodies. Although the magnetic saturation, Curie temperatures, and permeabilities are below the best alloys, their remarkably high resistivities—more than a million times higher than the metals—give excellent properties at very high frequencies used in television and communications.

Another fascinating device to which magnetic materials have contributed importantly is the digital computer. Magnetic cores are excellent bi-stable elements that never wear out. By rolling one of the molybdenum Permalloys extremely thin, to 0.000125 in., a material was found that combined the advantages of a rectangular hysteresis loop, with virtual elimination of the eddy currents that slow down the process of magnetization. While the human brain can be thought of as a memory storage with a tremendous number of storage elements far exceeding any built by man, the rate of operation of these storage elements is relatively low. Metallic tape cores permit access to, or storage of, information in a few millionths of a second with very little expenditure of energy. Evaporated metal films promise even higher speeds. The potential of digital computers in handling complex problems has scarcely been tapped. Obviously, the quantities of material used here are very small, but their importance is practically inversely proportional to their size.

In terms of size there is about 10^{10} difference in weight between the tiny memory or switching cores and the huge electro-magnetic cores now under construction for the newest particle accelerating machines.

A 3-bev proton Synchrotron employs about 500 tons of cores made from A-6 grade silicon-iron. And



this is one of the smaller machines. Some are being proposed that would employ as much as 60,000 tons of magnetic alloy.

In summary, magnetization curves for important soft magnetic materials are compared in Fig. 2.

Hard magnetic materials

In contrast to the high-permeability soft magnetic materials in which every effort is made to facilitate the process of magnetization, there are the permanent magnet or *hard* magnetic materials that make magnetization and demagnetization more difficult. To a large extent the creation of permanent magnet properties hinges on fine particles in the form of precipitates in alloys or in the form of assemblages of discrete particles.

The properties of a permanent magnet were perhaps already known to the ancient Chinese and were utilized by Columbus in discovering America. But progress in developing better, permanent magnetic materials has, like the soft magnetic alloys, paralleled the advances and needs connected with the uses of electricity. Up until World War I, the only major improvement over carbon steels used for centuries was the 6-pct W carbon steels. In 1917 a major advance was made for this type of material by alloying with about 36-pct Co. This improved the coercive force about four times and more than tripled the maximum energy product to about 0.9×10^6.

It was soon found that molybdenum could be substituted for part of the expensive cobalt. The resulting Remalloy was regarded as the forerunner of a new series of dispersion-hardened, carbon-free alloys from which most present day magnets are made.

The best material now available commercially is commonly known as *Alnico V*. This material was originally developed at the Phillips Laboratory in Holland. As the name implies, it is an alloy of aluminum, nickel, cobalt, and copper in iron. This aristocrat of a whole family of Alnico alloys has a maximum energy product of 4.5 to 6×10^6 and must be heat-treated in a strong magnetic field. Alnico magnets are now found in virtually all quality loudspeakers and many small motors and generators. Alnico V is hard and brittle and is cast into shape and ground to the required tolerances. Alnico V, as well as Alnico II or VI, can be pressed from powders into simple small shapes, usually weighing less than 20 g, and then sintered.

Although most permanent magnet materials tend to be hard and brittle, some magnet alloys can be forged and are even ductile enough to be cold rolled or drawn into wire.

For example, *Vicalloy*, a 10 pct V — 50 pct Co-Fe alloy can be rolled into sheets or drawn into wire. It is especially useful for magnetic recording tape. Similarly, *Cunico* permits making machinable magnets with a high coercive force, and *Cunife* can be drawn into wires with relatively high coercive force and energy product.

Permanent magnets are found in a myriad of applications, ranging from telephones, instruments, and watt meters, to thermostats, coffee makers, and toys. As with the high permeability materials, the cost is governed to a larger extent by the cobalt content, a major consideration in larger sizes of magnets. One useful alloy in which extremely high coercive force is required is *Silmanal*, which contains 86 pct Ag. One of the highest performance magnets used commercially contains 77 pct Pt. Oddly enough, iron, which in pure bulk form can be made to have very high permeability, is also capable of being made into excellent magnets when it is in the form of fine, elongated particles. Already Paine and his co-workers have made magnets of elongated iron particles with maximum energy products of over 3×10^6 gauss oersteds and over 5×10^6 gauss oersteds with cobalt-iron particles. Theoretically, it should be possible to attain maximum energies of 50×10^6 gauss oersteds with the cobalt-iron particles.

Fig. 3 shows demagnetization and energy product curves for some of the principal magnet materials used today.

Future of magnetic materials

The tremendous strides in development of improved magnetic materials have been greatly spurred by the technology's need for these materials. Actual demand and usage, however, is governed by the balance between need and cost. Here the skill of the metallurgist plays a vital role in developing practical and economical materials and methods used successfully today. A major challenge exists in improving the uniformity of the magnetic properties, as well as in developing new materials for the designer who constantly seeks more efficient and less costly materials to do a bigger job with smaller size and weight.

One of the fascinating possibilities in new materials is silicon-iron for generators and transformers in which two favorable crystal directions lie in the plane of the sheet (cubic texture) instead of the conventional grain-oriented silicon-iron used today with only one favorable direction in the plane of the sheet. The feat has been accomplished in several laboratories here and abroad, and intensive work is underway to determine the practical usefulness of the material as well as the feasibility of its production by reproducible and economic methods.

The increasing improvement of vacuum melting techniques can be expected to play a part in producing levels of purity hitherto unattainable. Better understanding of the mechanisms of deformation and recrystallization will lead to improvements in the level of quality and uniformity, although the outlook is that improvements in present soft magnetic alloys will become more difficult and challenging.

The increased use of ferrites in communications and the intensive research on these materials will, undoubtedly, lead to new materials and expanded usage, both for high frequency and permanent magnet applications.

There are still great potentialities for the fine, elongated particle permanent magnets of iron and iron-cobalt where the gap between results attained thus far and theoretical possibilities is still a full order of magnitude.

Even though the large-scale uses of magnetic alloys are likely to continue much as at present, we can expect greater specialization where the needs of automation, computers, atomic energy, and conquest of space will require magnetic materials with unusual properties, even at high cost.

The future for magnetic materials now appears far more challenging than when the first silicon iron was produced.

New Power Rolling Process

Dispersion strengthening principles may need revision when applied to larger powders—high strength and workability are features of product.

by S. Storchheim

A NEW, proprietary, high-energy powder consolidation technique has been developed which seems to shed new light on dispersion strengthening principles, and in addition yields materials which possess substantially higher strength properties, both at room and elevated temperatures. Powders are rolled in a conventional or vertical powder rolling mill in such a way that after passing between the rolls, the resultant strip is reguline in almost all respects. This means that the strip is not in the green compacted state as conventionally obtained, but rather has almost 100 pct of theoretical density.

Lead powders have been rolled with strengths as high as 8600 psi, compared to a maximum value of 2960 psi stated in the literature. Also, commercially pure aluminum powders have been rolled to strengths as high as 32,000 psi, and this has been increased to over 40,000 psi by additional cold rolling. Conventionally-produced, commercially-pure aluminum sheet has a maximum tensile strength of only 24,000 psi.

One of the major advantages of the new technique is that it can consolidate almost any size particle of almost any shape. It is here, working with powders from −325 mesh up to substantial sizes, that discrepancies with accepted dispersion strengthening principles have been noted.

It has been established that with SAP (sintered aluminum powder) products the maximum cold reduction that can be attained is approximately 30 pct. Further reduction causes micro-cracking with a loss of strength and ductility, and no appreciable increase in strength is obtained. However, this has not been found to be the case with powder-rolled materials using coarse starting powders. When −325 mesh material is used (17.5 μ diam), response to further cold reduction is almost identical to that of SAP-type materials. However, when coarse needle-like particles were utilized—even spheres of a large particle size, for that matter—cold reductions as high as 95 pct were attained with a continued increase in strength and no evidence of micro-cracking.

It is believed that the spacing theory of distance between refractory particles is no longer valid, at least not for larger sized powder rolled to strip by this new technique. Rather, the following is believed to occur: there are discontinuities on the surfaces of powder particles. The finer the particle, the more discontinuities there are per unit area. During high energy consolidation, coherency stresses are set up when particles are brought together, and the discontinuities are bonded. The more surface area available on the particles, the greater the actual number of discontinuities that are available for mismatch bonding.

Where extremely fine particles are used, such as SAP-type flakes and fine −325 mesh powder, there is a minimum amount of volume available in the particles to be cold worked, i.e., most of the dislocations are pinned down and the three dimensional dislocation continuity is not extensive. As such, the response to cold reduction is not particularly great. In the case of coarse particles, there is a considerable volume of *unworked* metal withing the original particles. As such, dislocations can be moved and reductions made well past the 30 pct limit of the fine materials. So long as there is sufficient volume available, cold working can continue to the higher percent reductions attained in this work without any deterioration of the properties.

Ansell[1] brought out the possibility that with lower extrusion ratios fewer of the dislocations would be pinned down, and the material should have the ability to be worked further. As such, the data in this work appear to coincide with his thoughts, only instead of using a lesser bonding energy, larger volumed particles were used to accomplish the same objective. This greater volume in the particles allowed for the availablity of unpinned dislocation sites, dislocation sources, and a continuous three dimensional dislocation network capable of accepting a very considerable degree of cold work. Of course, the oxide films can not be disregarded altogether, but their function seems to stem from a more macro viewpoint. It is believed that room-temperature properties are primarily a function of this ratio of surface area to volume and not so much that of percentage oxide content.

It was felt that powders which do not oxidize, such as gold or platinum, could be worked so that the surface area to volume hypothesis could be validated. As such, a few cursory experiments were conducted utilizing gold powders of −100 mesh and −325 mesh. These materials were consolidated into strip form, given a full anneal at 850°C for 1 hr, and then cold reduced 60 pct. The −100 mesh material attained a UTS of 41,300 psi. Compare this to 32,000 for cast-wrought gold 60 pct cold reduced. Not only did the powder-rolled gold evidence strengths greater than that of the normal cast-wrought material, but in addition, the strip made from the finer-sized powder in itself attained a considerably higher value than the strip made from the coarser powder.

As a corollary to the theoretical considerations discussed above, hot explosive compacting experiments were run on the same lead powders; the results, which gave further evidence in support of the theory, have been reported elsewhere.[2]

It is apparent that further work on dispersion hardening is required for a true understanding of the principles involved. Also, techniques, other than hot pressing followed by hot extrusion, should be considered.

S. STORCHHEIM is President, Storchheim Research and Development Corp., Woodside, N. Y.

[1] G. S. Ansell: A Proposed Mechanism for the Strengthening of SAP-Type Alloys, *AIME Trans.*, vol. 215, no. 2, pp. 294-295.
[2] A. Cross: *The Iron Age*, Dec. 24, 1959, pp. 48-50.

END-POINT TEMPERATURE CONTROL IN LD STEELMAKING

As a means of effecting better control of end-point temperatures at the Jones & Laughlin oxygen furnace plant, a set of mathematical equations has been developed. These are the product of a thermochemical analysis of the process and are designed to calculate the required scrap, lime, and hot metal additions in terms of a number of independent variables. Results of test heats were encouraging enough to warrant adoption of this technique by the production dept.

by W. J. Slatosky

THE autogeneous nature of the basic oxygen (LD) steelmaking process makes it possible to control bath temperatures without an external fuel supply by charging the vessel with additions that are thermally balanced. The thermal requirements of the charge materials are such that, during the refining process, they throttle the heat generated by the metallurgical reactions in a manner designed to result in a specified temperature at the completion of the heat.

In the past, operating personnel at the basic oxygen furnace plant of Jones & Laughlin's Aliquippa works relied on their experience and technical knowledge of the process to determine the quantities of charge additions needed to result in a finishing temperature in the range 2880° to 2920°F. (The charge consists primarily of 93 tons of scrap and hot metal plus an amount of lime sufficient to maintain a basicity ratio of 2.8 to 3.2). Estimates of required quantities of these materials are based on a consideration of the effects on finishing temperature of 1) iron silicon content, having a variation of 0.8 pct to 1.8 pct; 2) iron temperature, ranging from 2250° to 2600°F; and 3) any excessive cooling of the furnace caused by a production delay. The end temperature of the preceding heat also serves as a guide, in that, if a heat was within the specified temperature range, the succeeding heat could be charged with materials of nearly the same proportions (provided the hot metal in each case was of approximately the same temperature and composition). Conversely, if a heat was outside the specified tapping range, or if the hot metal used in that heat was of different analysis and temperature from that of the iron to be charged, an adjustment in the proportion of additions is in order for the following heat.

Because of the complex thermochemical behavior of the process and the inexact and subjective nature of this method of determining charge additions, precise temperature control is not to be expected. Therefore, those heats outside the specified tapping range necessitated subsequent adjustments by either reblowing the cold heats for a suitable length of time so as to elevate the bath temperature to the desired level, or cooling hot heats with a proper amount of scrap.

In an attempt to devise a method for improving temperature control, an analysis of the thermochemistry of the process was undertaken. This, in turn, led to the development of a set of mathematical equations which make possible the calculation of the quantities of scrap, lime, and hot metal needed to attain the specified tapping temperature range. The analysis is not intended to be a repetition of work done by others such a McMulkin[1] or Philbrook[2]. It is meant to be an extension of their work so that charge additions can be calculated not in terms of silicon alone but, rather, as a function of all independent variables. This paper presents the derivation of these relationships, a method of utilizing them on an operational basis, and illustrates their effectiveness in controlling bath temperatures.

Heat balance

The first step in analyzing the problem was the enumeration of the pertinent variables, which were separated into the following three categories: important variables, variables considered as constants, and variables to be neglected (Table I). The breakdown is an arbitrary one, designed to facilitate the

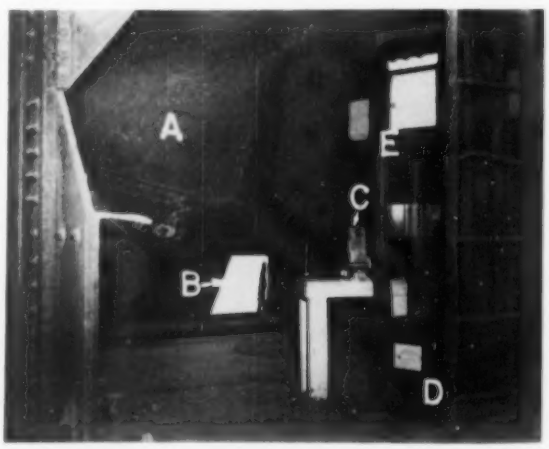


Fig. 1—Experimental arrangement of two-color pyrometer and accessories: A is mixer ladle, B molten iron stream, C sensing head of pyrometer, D power supply of pyrometer, and E recorder.

W. J. SLATOSKY is a research physicist with Jones & Laughlin Steel Corp. This paper was presented at the 1960 AIME Annual Meeting.

analysis; otherwise, the mathematical treatment would have been exceedingly cumbersome and complex. Experience has shown that these simplifying assumptions do not seriously impair the accuracy of the calculations.

These variables, along with the limiting assumptions listed in Table I, were then used to write a heat balance for the process by applying the equation of continuity:

Rate of Increase of Heat	=	Rate of Income of Heat	—	Rate of Outgo of Heat	[1]

In its simplest form, this balance appears as follows:

Rate of Heat Gain by Hot Metal = Rate of Heat Generation by the Enthalpy Changes for the Following Reactions occurring at 77°F:

$$Fe_3C + \frac{1}{2}O_2 = 3Fe + CO$$

$$Fe_3C + O_2 = 3Fe + CO_2$$

$$Fe_2Si + O_2 + 2CaO = Ca_2SiO_4 + 3Fe$$

$$Mn + \frac{1}{2}O_2 = MnO$$

$$2Fe_3P + \frac{5}{2}O_2 + 4CaO = Ca_4P_2O_9 + 6Fe$$

$$Fe + \frac{1}{2}O_2 = FeO$$

$$Ti + O_2 = TiO_2$$

+ Rate of heat radiation from flame to bath

— Rate of heat loss through lining

— Rate of heat absorbtion by dissociating mill scale and ore pellets

— Rate of heat absorbtion by melting scrap

— Rate of heat absorbtion by uncombined lime

— Rate of heat loss by fume generation. [2]

For convenience in calculation, all reactions are assumed to occur at 77°F. The choice is an arbitrary one, since the enthalpy change depends only on initial and final temperatures and is independent of the reaction temperature.

It is observed that the heat balance has been expressed in the form of rate equation. This approach stems from a dynamic analysis undertaken on the Jones & Laughlin analog computer, in which differential equations were used to define completely the transient behavior of the variables. Computer calculations demonstrated that the rate equation could be integrated to yield finishing temperatures that compared very well with measured values. It was also determined that by transforming the integrated expression and supplementing it with several other relationships, calculations could be made for obtaining thermally-balanced charge additions

Rather than begin using these expressions immediately to control furnace charges, it was decided that it would be wiser to work alongside operating personnel and predict end-point temperatures. Such a procedure would enable these people to gain confidence in the mathematical model, and, at the same time, would permit refinements to be made in the equations. After a suitable testing period, the transformed relationships could then be used to test control the process.

End-point temperature equation

The derived end-point temperature equation is of the form

$$T_F = [W_{HM}(87.35 + 0.255\,T_M + 131.4\,Si_o + 30.34\,Mn_o) + 16.47\,W_s + 29.57\,W_{CaO} + (2.26\,V.V. + 19.93)\,(10^s) - 3125\,T_M - (121.4 \times 10^s - 1618\,W_s)(-75 \times 10^{-5}\,L.H. + 0.153) - 1225\,(W_{MS} + W_p)] \div [W_{HM}(0.211 + 0.0041\,Si_o + 0.00025\,Mn_o - 285 \times 10^{-s}\,T_M) + 0.214\,W_s + 0.384\,W_{CaO} + 140\,V.V. + 0.19\,(W_{MS} + W_p) + 1225 - (7{,}500 - 0.10\,W_s)(-75 \times 10^{-5}\,L.H. + 0.153)] \quad [3]$$

where

T_F	=	the end-point temp (°F)
W_{HM}	=	wt of hot metal (lb)
T_M	=	measured Fe temperature (°F)
Si_o	=	measured Fe Si (pct)
Mn_o	=	measured Fe Mn (pct)
W_s	=	wt of scrap (lb)
W_{CaO}	=	wt of lime (lb)
V.V.	=	basicity ratio (dimensionless)
L.H.	=	lance height (in.)
W_{MS}	=	wt of mill scale (lb)
W_p	=	wt of ore pellets (lb)

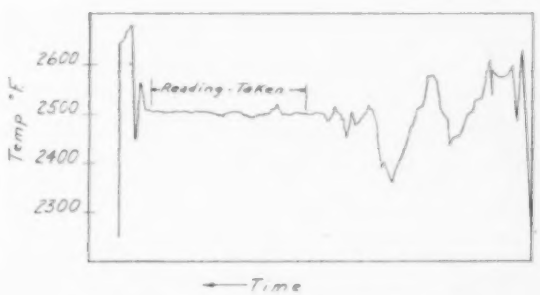


Fig. 2—Sample of two-color pyrometer recorder trace.

Fig. 3—Operation of the slide rule computer at the basic-oxygen plant.

A set of computed values is presented in Table III to illustrate the effects that certain changes in these parameters have on end-point temperature.

It is noted that the quantities C, CO, CO_2 SiO_2, MnO, and FeO do not appear explicitly in the preceding expression. The reason is that these items have been expressed as functions of the independent variables, so their thermal effects are incorporated into the equation even though this is not apparent. Still other quantities such as P_2O_5, TiO_2, flame radiation, fume losses, heat losses through the furnace lining, lance or oxygen input, and finished steel chemistry have been approximated with a set of constant values (See Table I).

Results of mill trials

The next step was to conduct a series of mill trials to compare calculated end-point temperatures with measured values. The trials were conducted from November 1958 through March 1959, during which time predictions were made for 323 heats. The calculations necessitated utilization of the following data: weights of mill scale, scrap, lime, and hot metal, plus lance height position above the metal bath (all determined by the melters), as well as measured iron chemistry and iron temperature. The iron analysis had been determined previously from blast furnace runner tests, while iron temperature was measured with a two-color pyrometer[3] sighted on the metal being poured from the mixer ladle into the charging ladle.

The experimental arrangement of the two-color pyrometer and accessories is shown in Fig. 1, and a sample temperature recording is presented in Fig. 2. Temperature oscillation during the initial stages of the pour is caused by smoke obstructing the pyrometer's field of view and by voids in the stream. Later, the trace becomes stabilized because the stream becomes more compact and the smoke is dissipated by an electric fan. It is during this period of stability that the temperature reading is made. The oscillations appear again for a brief interval at the end of the pour when the mixer ladle is turned to its rest position.

The two-color pyrometer was selected for iron temperature measurement not only because of its accuracy, which compares very favorably with that of a thermocouple, but also because it is completely automatic, thus obviating the need for an operator.

It should also be pointed out that when the hot metal is poured into the furnace, a temperature drop will have occurred as a result of heat losses incurred during transit from the pouring pit to the charging floor. An equation was derived for computing this temperature drop, and the iron temperature as it appears in the heat balance has a correction factor applied to it.

With this information, on-the-spot calculations of finishing temperatures were then made with a special slide rule type of computer designed from Equation 3. The computer made it possible to predict the end-point far in advance and with a high degree of accuracy. Its operation is illustrated in Fig. 3.

During the trial period, 249 of the 323 calculated heats, (77 pct) fell within 20°F of the temperatures measured at the endpoint, and 297, or 92 pct, were within 30°F of these measured values. A frequency distribution of the number of heats versus the difference between the measured and calculated temperatures is displayed in Fig. 4. In view of the excellent results of these trials, it was concluded that the model was theoretically sound and might possibly be used for controlling bath temperatures.

Control equations

To develop the required control equations, it was necessary to derive, in addition to the relationships used to predict end-point temperatures, a relationship for computing lime and another for computing hot metal. Now, instead of solving for tap temperature, the stipulation was made that all heats were to be turned-down within the range 2880° to 2920°F.

Table I. Thermodynamic Variables of the Basic Oxygen Steelmaking Process

Major Variables
- Iron Chemistry (C, Si, and Mn)
- Iron Temp
- Wt of Slag Constituents at Turn-Down (MnO, CaO, SiO_2, and total FeO)
- Wt of Charge
- Wt of Scrap
- Wt of Hot Metal
- Wt of Mill Scale
- Wt of Ore Pellets
- Wt of Drain Outs
- Delay Times
- Lance Height Above Bath
- Basicity Ratio

Variables Considered as Constants
- Blowing Time (Relatively constant for a given oxygen flow rate, turn-down carbon level, and weight of charge)
- End-Point Chemistry (C, Si, Mn, P, and Ti)
- Iron Chemistry (P and Ti)
- Fume Losses
- Ratio of CO and CO_2 Formed in the Bath
- Slag Constituents (TiO_2 and P_2O_5)
- Heat Lost through the Furnace Lining

Variables to be Neglected
- Scrap Size
- Scrap Chemistry
- Quantity and Chemistry of Iron Slag
- Age of the Furnace Lining
- Slag Constituents (MgO and Al_2O_3)
- Condition of the Furnace Lining
- Wt of Fluorspar

Table II. Assumptions Used to Write the Heat Balance

1. 95 pct CO and 5 pct CO_2 formed in bath.
2. CO and CO_2 leave furnace at avg temp of 2700°F.
3. All SiO_2 and P_2O_5 combine with lime in slag.
4. Amount of fume loss a constant of 10,000 lb per heat.
5. Fumes leave at avg temp of 2700°F.
6. Slag and metal have same temp at turn-down.
7. FeO and Fe_2O_3 in the slag replaced by total FeO.
8. Heat losses are for a steady state.
9. Compositions of ore and mill scale are 47.5 pct Fe_2O_3 and 47.5 pct Fe_3O_4.[3a]
10. For consistency it is necessary to place minus signs in front of all enthalpy terms, since such changes are negative for exothermic reactions and positive for endothermic reactions.
11. All heats are blown to approx 0.05 pct C in about 20.5 min with an oxygen flow rate of 6500 cu ft per min.
12. Specific heats are assigned avg constant values applicable from 77°F to finishing temperature. They are designated by the symbol C_p' to distinguish them from the temperature dependent specific heat C_p.

Table III. Effects of Changes in the Independent Process Variables on End-Point Temperatures

(Note: Calculations were made on the basis of a charge consisting of 58,000 lb of scrap, 128,000 lb of hot metal, and 13,000 lb of lime.)

Variable	Amount of Change	Effect on End-Point Temp, °F.
Si	0.10 pct	36
W_{HM}	1000 lb	7
T_M	100°F	62
Mn	0.10 pct	8
W_S	1000 lb	12.5
V.V.	0.1	4
W_{MS} or W_P	1000 lb	32
W_{CaO}	1000 lb	23
L.H.	10 in.	4

Thus, finishing temperatures became an independent variable, while scrap, lime, and hot metal were made dependent. It must be pointed out that the charge additions: mill scale, fluorspar, and ore pellets (when used) are chosen at the discretion of the melters; so, they are not obtained from the control equations. These expressions are of the form:

Hot Metal

$$W_{HM} = W_C - W_s \qquad [4]$$

Lime

$$W_{CaO} = \left(\frac{60.06}{28.06}\right)\left(\frac{1}{0.92}\right)$$

$$(V.V.)\left(\frac{Si_o}{100}\right)(W_{HM}) \qquad [5]$$

Scrap

$$W_s = \{W_C[(117.93 - 25.3\ V.V.)(Si_o) + 29.41(Mn_o) + 0.257\ (T_M) - 502.19] + 1.8 \times 10^6\ (V.V.) + 16.22 \times 10^6 - 3125\ (T_M) - 96.3 \times 10^6\ (-75 \times 10^{-6}\ L.H. + 0.153) - 1808\ (W_{HM} + W_p)\} \div \{(117.93 - 25.3\ V.V.)(Si_o) + 29.41\ (Mn_o) + 0.257\ (T_M) + 93.82 - 1285\ (-75 \times 10^{-6}\ L.H. + 0.153) - 67\ t_D\} \qquad [6]$$

Where

W_C = charge weight (lb)

t_D = time of delay between tapping of one heat and the charging of the next (min). This is refinement that had not been used in the finishing temperature equation, and it is designed to compensate for the heat lost from the lining during a delay.

Other symbols are defined in Eq. [3].

It must be emphasized that the form of the scrap equation will vary slightly with different oxygen flow rates and with different finishing carbon levels, because such changes will affect the lancing time, the total heat losses, and the final slag and steel chemistry. (The above expression is valid only for heats finished at 0.05 pct C with an oxygen flow rate of 6500 cu ft per min, but by modifying certain coefficients, the equation can be adapted to higher carbon content and different oxygen flow rates.)

To illustrate the effects that the two most important variables, iron silicon and iron temperature, have on the required scrap additions, a plot of scrap versus silicon with iron temperature as a parameter has been constructed from the scrap equation (Fig 5).

Mixer ladle drain-out equations

As an additional refinement to the mathematical model, expressions were developed for approximating the average temperature and composition of a hot metal addition that might consist of a mixture of a drain-out from one mixer ladle and the balance from another that is of different temperature and

Table IV. Causes of Off-Temperature Heats

1. Erroneous Fe temp measurements (caused by smoke)
2. Non-Representative chemical analyses
3. Excessive slag volume caused by erratic lancing conditions
4. Excess oxygen or lance time
5. Use of pit scrap
6. Long delays
7. New furnace lining
8. Computational error
9. Error in the mathematical model
10. Error in weighing additions
11. Unmelted scrap at completion of the heat

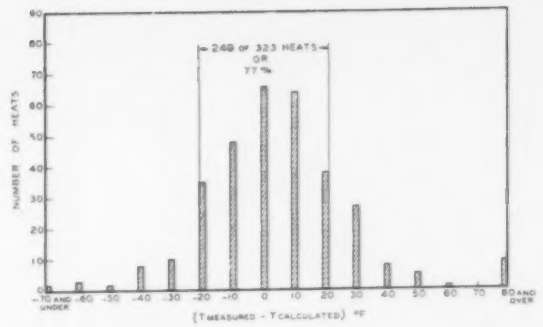


Fig. 4—Frequency distribution of difference between calculated and measured end-point temperatures.

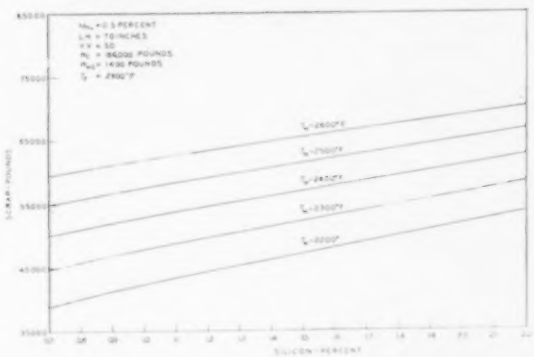


Fig. 5—Plot of scrap vs silicon with iron temperature as a parameter.

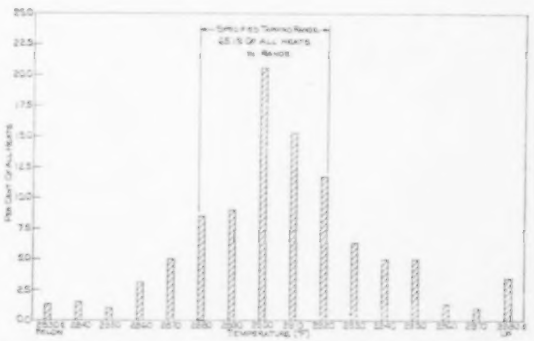


Fig. 6—Distribution of test heats (made with aid of mathematical model) with respect to finishing temperatures.

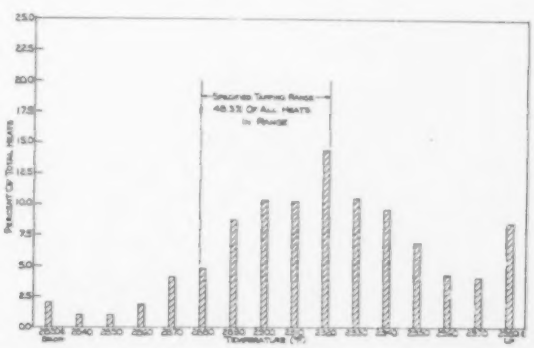


Fig. 7—Composite of heats made without aid of mathematical model.

composition. The importance of these relationships becomes apparent when it is considered that a drain-out situation is encountered about once in three or four heats with the probability being in favor of having a difference in temperature and composition between the two batches of metal comprising the mixture.

Equations are needed for determining only silicon, temperature, and manganese, since carbon is never measured but, instead, is calculated from the iron silicon content and iron temperature, while phosphorus and titanium are assigned constant values. The form of these expressions is as follows:

Avg Si

$$Si_A = Si_B + \frac{(W_{DO})\ (Si_{DO} - Si_B)}{130{,}000} \qquad [7]$$

Avg Temp

$$T_A = T_B + \frac{(W_{DO})\ (T_{DO} - T_B)}{130{,}000} \qquad [8]$$

Avg Mn

$$Mn_A = Mn_B + \frac{(W_{DO})\ (Mn_{DO} - Mn_B)}{130{,}000} \qquad [9]$$

Where

subscript A = an avg value

subscript B = the balance

subscript DO = the mixer ladle drain-out

Process test control

During a trial period extending from April 6 to May 9, 1959, 227 heats were charged with additions calculated from the mathematical model, using the following procedure to determine the charges: Near the end of the refining period of one heat, approximately 100,000 lb of hot metal were poured from the mixer ladle into the iron charging ladle to obtain a temperature reading with the two-color pyrometer. The temperature, along with the iron analysis, plus the melter's selection of lance height position, weight of mill scale, and weight of lime were then used to compute the scrap addition by means of a slide rule designed from a simplified version of Equation 6. After the scrap weight was calculated, the hot metal was obtained by employing Equation 4. This information was passed on to the melter who would then have his crew weigh out the calculated charge materials.

It is noteworthy that the entire procedure was carried out without causing any delay in charging the succeeding heat. It must also be pointed out that the lime used in the calculations was an estimate of that required to yield a given V. Value. Such an estimate will not be required in the future, as Equation 6 contains lime as an implicit rather than an explicit variable.

All the test heats were finished at 0.05 pct C with an oxygen flow rate of 6500 cu ft per min. The endpoint was determined visually by the melter after which the furnace was turned-down and a temperature reading taken with an immersion thermocouple. If the heat was within the specified temperature range, it would be tapped immediately; if it was too hot it would be cooled with a suitable amount of scrap; and if it was cold, it would be reblown for an appropriate period of time.

Of the 227 test heats, 148, or 65.1 pct, were within the desired range at completion of the heat. The graph in Fig. 6 shows how the test heats were distributed with respect to finishing temperatures. In comparison, a composite of the heats made *without* the aid of the mathematical model during the time of the trials is illustrated in Fig. 7. Note that, in addition to the 16.8 pct improvement over the composite performance, the heats computed with the slide rule are normally distributed, whereas the other heats yield a distribution that is skewed.

The mill trials demonstrate that improved temperature control with the use of the mathematical equations is feasible. However, adjustments are still required 35 pct of the time. Numerous reasons can be advanced to explain the occurrence of off-temperatures—a list of the more significant of these is presented in Table IV. It is believed that the temperature performance level can be raised considerably by exerting greater control over some of these anomalous conditions, i.e., by having a more powerful fan for removing smoke from the iron reladling stream, by taking iron samples from the mixer ladle to obtain a better analysis, and by effecting better control of oxygen input time.

Conclusions

Results of test heats made at the Jones & Laughline basic oxygen furnace plant demonstrate that a set of mathematical equations derived from thermochemical principles can be used to calculate thermally-balanced charges. Using controlled charges, a greater percentage of heats can be turned-down within a specified tapping temperature range than is otherwise possible.

The charges were calculated with a special purpose, slide rule type computer, designed from the mathematical model. However, it was decided that an electronic computer would be better suited for use by operating personnel, not only because of its greater accuracy but also because it is easier to operate than the slide rule. Such a device is now on order, and installation will be made within a few months. It is expected that the reduced number of off-temperature heats resulting from the use of this instrument will be accompanied by significant financial returns.

Much effort must be expended before work in this area can be considered complete. In fact, the application of computer techniques to the control of the process has only begun, and the future can well expect to see the computer being used for the calculation of blowing times and, consequently, the control of steel *chemistry* as well as temperature control.

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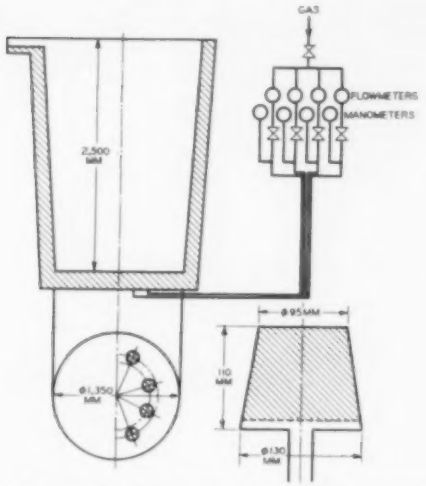


GAZAL FOR IRON DESULFURIZATION

At the Pompey steel plant in France, desulfurizing tests have been concluded with the Gazal process. Results are considered successful, and industrial application at Pompey is expected when changes to acid blast-furnace practice are undertaken.

Abstract of a metallurgical report by
Societe des Acieries de Pompey, France

IN the past few years, many processes for desulfurizing hot metal have been tried. The Gazal process accomplishes this end by introducing compressed air or nitrogen into the molten bath by means of a porous refractory plug in the ladle bottom, thus creating a turbulence which speeds the necessary slag-metal reactions. Invented by M. Etienne Spire, Gazal desulfurization tests were performed at the Pompey steel plant in France, in collaboration with the Societe Air Liquide, owner of the Gazel patents.

Method of operation

Four porous plugs are arranged, as shown in Fig. 1, in the bottom of a silico-alumina lined ladle. After iron from the blast furnace is deslagged, it is poured into this treatment ladle, the bottom of which has been covered with a mixture of sodium carbonate and sodium chloride to insure a liquid slag. During pouring, a light flow of gas is maintained through the plugs. And after pouring is complete, gas flow is increased to 9 cu m per hr for each plug; treatment is continued for 10 min. Deslagging takes place afterwards, with a light flow of gas being maintained during this operation to agitate the batch and push slag toward the spout.

In earlier tests, nitrogen was used in a quantity of 0.3 cu m per metric ton of iron treated, but in later experiments compressed air (6 kg per sq cm) from the plant line was used. The change from nitrogen to compressed air did not show any diminution in the rate of desulfurization, due to the small quantity used.

Results

With iron containing less than 0.100 pct S, from 5 to 10 kg of sodium carbonate per metric ton of pig iron was found necessary, and desulfurization was between 70 and 90 pct. A slight increase in desulfurization was observed with more carbonate, but 6 kg per ton was found to be sufficient to insure 0.020 pct S or less in all cases.

With iron resulfurized to 0.100 to 0.200 pct S, 8 kg of carbonate per ton was added, and desulfurization ranged between 70 and 80 pct, the average change being 0.110 pct S.

Temperature: Experiments were performed after the iron had been transferred from a mixer, making the pre-treatment temperature quite low, around 1180° to 1200°C. It was found that the quantity of sulfur eliminated increased with increasing temperature, so it would seem advisable to treat the metal before pouring into the mixer.

Silicon content: Desulfurization increases when the hot metal is high in silicon, rates between 80 and 90 pct having been achieved when the iron analyzed 0.50 pct Si before treatment. Loss of silicon during treatment was generally found to be between 1 and 1.5 times the loss in sulfur. This remains constant whether nitrogen or compressed air is used.

Temperature loss: Median loss of temperature during treatment was found to be below 40°C, with the cooling effect of the gas considered to be entirely negligible.

Final slag: The final slag, which is quite fluid and contains no metallic granules, has the following partial analysis: 7 pct S, 5 pct FeO, 7 pct free SiO_2, 26 pct SiO_2 in the form of silicate of soda, and less than 1 pct CO_2. Slag produced amounts to less than 20 kg per metric ton pig iron, and iron loss is less than 1 kg per ton.

Economics and conclusions

With sulfurous and siliceous acid pig iron containing 0.5 pct Si and 0.15 to 0.20 pct S for example, an addition of 8 kg of carbonate per metric ton pig iron will desulfurize at least 80 pct, yielding a final sulfur of 0.030 to 0.040 pct. Volume of gas used is small and losses of iron are negligible. The porous plugs developed have been used for as many as 100 heats, and it would seem to be an easy task to make them readily changeable.

With results in from more than 100 experimental heats, it is apparent that the process is entirely suitable where a large amount of desulfurization is necessary—such as pig iron from acid blast furnaces. While it is known that desulfurization increases with increasing silicon content, no experiments have been run with silicon greater than 1 pct. This would seem to be an interesting area for further work.

ROTARY REACTOR

DESULFURIZES AND DESILICONIZES

Applications of Diamond Alkali Co.'s Rotary Reactor in the ferrous metals industry are described. Its performance as a desulfurizer and desiliconizer has been established, but development work using the reactor for dephosphorization, decarburization, and direct reduction has yet to be undertaken.

A Staff-Written Summary

DESULFURIZATION and desiliconization external to ironmaking and steelmaking furnaces has been the object of considerable research in recent years . . . particularly in Europe where the sulfur problem has been greater than in the US. But even in this country sulfur shows signs of becoming a more important problem with the increased use of imported ores, and it is already a problem in foundry practice.

Desiliconization, on the other hand, has been explored with some interest during the past few years as a means of decreasing the tap-to-tap time of the open-hearth process, thereby increasing furnace output in order to permit more effective competition with the high-output rates of the oxygen steelmaking processes.

In the US, the Diamond Alkali Co., already involved in desulfurization through the sales of reagents, set about working out a more effective desulfurization process. The result was the design of the high-speed rotary reactor by Norman Goss, a consultant for Diamond Alkali.

The reactor has three main sections. 1) Base, serving as the foundation, it is complete with variable speed drive and drive rollers. 2) Refractory-lined rotor, supported by rolls at its two tires, it has a dam at the inlet end and is open at the discharge end to facilitate metal removal. 3) Refractory-lined hood, can be rolled forward so that it encompasses the open end of the rotor to receive the discharged metal. At the base of the hood is a discharge runner for hot metal, while an exhaust duct is arranged for fume control.

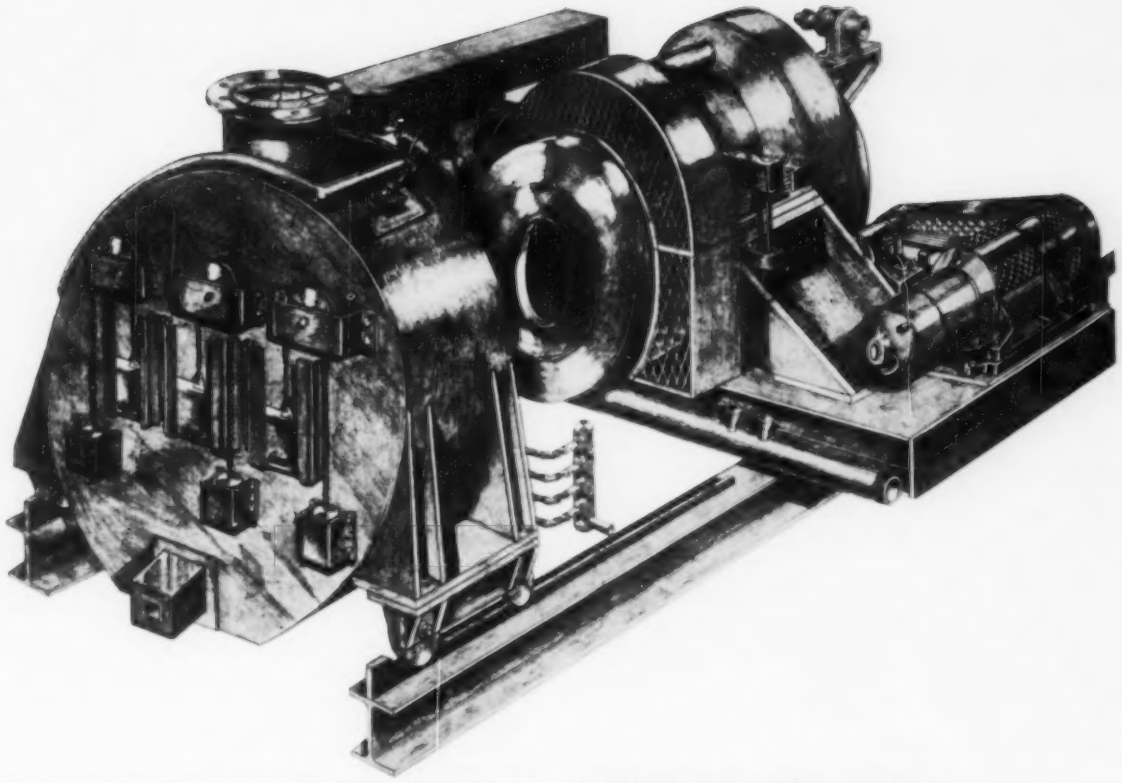
In order to preheat the reactor, one gas burner is situated in the hood; a second is on a pivoting support at the inlet end of the rotor. Treating additives, stored in a hopper situated above the inlet end of the machine, are introduced through a water-cooled tube which extends into the inlet end of the rotor.

The effectiveness of the rotary reactor was investigated in a detailed development program carried out by Battelle Memorial Institute. Tests were undertaken with a 10-tph reactor having a 3-ft long rotor with an inside diam of 10 in. Of prime interest was the evaluation of various chemical additives and the effect of temperature, reaction time, and rotational speed. Desulfurization materials, such as calcium carbide, lime, soda ash, and caustic soda were tried, and iron ore and oxygen were used on desiliconizing tests. It proved possible to reduce silicon from 1.27 pct to 0.40 pct simultaneously with desulfurization. In addition, the phosphorous level was reduced by as much as 28 pct during this treatment.

After three years of experimental work, a 60-tph reactor was built and installed in an Ohio foundry for a 6-month desulfurization test program under production conditions. This machine has a 6-ft long rotor with an inside diam of 24 in. Results of this work, completed only recently, revealed that no significant problems were entailed in applying the process to full commercial operation.

Desulfurization treatment

Treatment begins with hot metal flowing through the inlet runner into the revolving rotor. Held to the inner wall by centrifugal force, the metal forms a 1 to 2 in. thick layer covering the entire surface. Near the stream of incoming metal, the treating agent is added in solid, liquid, or gaseous form. As the material builds up a head against the dam at the inlet end of the rotor, a turbulent, helical flow takes place toward the discharge end of the rotor. Thus, there are four conditions present which cause intimate contact between molten metal and treating agent. These are 1) maintenance of a thin layer of metal, hence large surface area, during reaction; 2) turbulent action resulting from flow of metal through the rotor; 3) use of an additive of small particle size or gaseous form; and 4) centrifugal force causing the layer of treatment mate-



rial to be pressed against the surface of molten metal.

That these conditions do effect high reaction efficiencies has been verified during the development program. With the pilot reactor, iron was repeatedly desulfurized from 0.11 pct to lower than 0.02 pct, and results obtained with the 60-tph unit showed sulfur reduced from an average of 0.08 pct to less than 0.02 pct. This is on the basis of a retention time of 10 to 20 sec within the rotor.

Treated metal and slag leaving the rotor are collected in the hood and flow continuously out through the discharge runner. If desired, slag separation may be attained by damming and skimming the flow in this runner.

Temperature losses are reduced to a minimum by carrying out the reaction within a closed or balanced draft system. After the 60-tph reactor had reached thermal equilibrium, a maximum temperature drop of 45° to 75°F was experienced. If operations are intermittent, preheating is required.

Fume control is attained by maintaining a balanced draft within the reactor by means of a butterfly damper in the hood exhaust duct. This control has proved successful during heavy treatment with highly alkaline materials.

Most strongly alkaline treating agents, when used in ladle treatment, readily attack refractory linings and cause acute maintenance problems. But within the Rotary Reactor, the additive does not come in contact with the refractory due to the formation of a protective layer of metal on the inner rotor wall. The 2-in. refractory lining in the smaller Rotary Reactor endured numerous test heats and showed no effects from thermal shock or chemical attack. Similar results were obtained with the larger unit, although the lining thickness was proportionally greater.

Applications of the reactor

The rotary reactor seems applicable to a variety of uses in the steel industry. Features such as the assurance of intimate contact between metal and additive, refractory protection, and fume control are desired in most chemical reactions utilizing hot metal.

The most immediate application is probably in the treatment of blast-furnace hot metal. The reactor makes possible the simultaneous removal of both sulfur and silicon. This can be accomplished by treating with preheated iron ore and oxygen together with an alkaline desulfurizing agent in one rotary reactor. At the same time, the phosphorus level is also lowered. It should be noted, however, that better efficiencies would be expected if desiliconizating and desulfurizing treatments were carried out in separate reactors.

Decarbonization could also be effected in the rotary reactor. It is thought that steelmaking would involve a two-reactor series. Sulfur, silicon, and some phosphorus would be removed in the first, while removal of carbon and the remaining phosphorus would be the role of the second reactor. No development work on decarburization has actually taken place, although up to 13 pct of the carbon has been removed during desulfurization and desiliconization in the reactor.

The rotary reactor of Diamond Alkali Co. has shown itself to be an effective desulfurizer in pilot-plant work and in foundry operations. Research has also shown that it can effectively be used for desiliconizing. It has not yet been used by any steelmaker, but its application to the treatment of blast-furnace hot metal seems obvious.

The principles of this centrifugal reactor might also find application in decarburization and iron-ore reduction. Thus, a steelmaking operation might be built around a series of these reactors.

new use for radioactive tracers...

CHECKING FURNACE ATMOSPHERES

A simple arrangement, using Kr^{85}, keeps tab on operation of heat-treating furnaces.

by C. O. Reiser and K. L. Wilson

HEAT treatment of certain metal parts in the aviation and missile industry requires rigid control of the atmosphere inside the heat-treat furnace. As the furnace ages, erosion in the furnace lining and changes in other parts of the furnace system itself may cause the atmosphere to vary beyond acceptable limits, resulting in undesirable decarburization of heat-treated parts.

The technique described here is a simple, economical method for determining both the gas flow inside a heat-treating furnace and the concentration of the remaining original atmosphere at any time after a purging procedure has been initiated.

Kr^{85} checks atmosphere

This technique involves the use of a radioisotope of krypton as a radioactive tracer. The Kr^{85} is injected into the furnace through the purging or endothermic gas line. It betrays its presence by the emission of beta particles, which can be used to indicate several things about the interior of an operating furnace.

For example, the degree of purging in a furnace atmosphere is shown by the decreasing activity, or count rate, of krypton in the furnace. When this decreases to one ten thousandth of its original value, the atmosphere inside the furnace will contain only 100 ppm of the original atmosphere, that is,

$$\frac{\text{final count rate}}{\text{initial count rate}} \times 10^6 = \text{ppm of original atmosphere left.} \qquad [1]$$

In this way, final concentrations of the order of 100 ppm can be measured with an accuracy up to 1 pct using conventional, commercially available, and relatively inexpensive equipment. Accuracy limits come from possible electronic drift and minor variations of the krypton in the furnace caused by incomplete mixing of the gas within the furnace.

Description of equipment

In order to detect the Kr^{85} inside the furnace, the furnace atmosphere must be sampled. The method of sampling will vary with the construction of the individual furnace, but thermocouple ports usually provide a means for inserting a piece of ¼-in. stainless steel tubing. A continuous stream of gas from the interior of the furnace can then be drawn out, using a low-capacity pump.

This stream is passed through a sample chamber in which a counting head is mounted to detect the beta particles. The basic function of this sampler is simply to provide a means of taking a sample of the gas from the furnace and holding it long enough to make a counting run of suitable duration, usually about 1 min. In operation, all valves are opened and a stream of gas from the furnace is pulled through the chamber. When it is desired to count a sample, a valve between the pump and sample chamber is closed, and a sample of the gas from the interior of the furnace is trapped in the sample chamber, ready to be counted.

The cylindrical sampler has a mylar window near the top to permit beta particles to be seen by the counting head.

The counting head contains a phosphor which gives off small light pulses when the beta particles pass through it. These light pulses are, in turn, detected by a photomultiplier tube and converted into small voltage pulses. These voltage pulses are then amplified in the linear amplifier and counted in a scaler. The scaler is a direct-reading instrument and gives, within a certain statistical accuracy, the actual number of particles that entered the phosphor during a selected unit of time (usually 1 min) in terms of counts per minute.

Very low concentrations

The technique for concentrations below 100 ppm involves the use of counting foils. These foils are pieces of aluminum foil, about 5 mils thick, inserted between the mylar window of the sampler and the scintillation head. They serve to cut the count rate down so that it can be mechanically registered by a conventional scaler. When the count rate with the foils in has decreased to the point that the foils can be removed and the count rate still not overload the scaler, a count rate is measured with the foil in and then with the foil removed. This establishes a relationship for the count rate vs time curve taken with and without the foils.

As can be seen from an examination of Eq. 1, the higher the initial count rate, the lower the concentration that can be measured. Conventional scalers

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can normally count up to about 850,000 counts per min. Thus, using 100 cpm as a final count rate, a conventional scaler without using foils can measure a concentration of 120 ppm. The use of foils allows the same scaler to measure down to 0.1 ppm with about the same accuracy.

A typical study

During an actual test to determine the minimum purging time of a 750 cu ft furnace, the radioactive krypton was injected into the endothermic gas line as it left the gas generator. The *endo gas*, carrying the krypton with it, entered the furnace through evenly-spaced ports around the bottom of the furnace. The volume of krypton used was about 1 cu cm. Compared to the normal volume of endo gas flowing into the furnace, this was insignificant and, thus, did not in any way alter furnace operation.

The krypton reached equilibrium distribution inside the furnace within 10 min of the time it was initially injected into the endo gas line. The furnace atmosphere was sampled through three thermocouple ports, spaced at the bottom, center, and top of the furnace, and also at the outlet gas line from the furnace. The sampler was purged by means of alternately filling it with furnace gas and evacuating it with a vacuum pump before actually counting the krypton in the atmosphere.

Theoretically, there are two mechanisms by which the endo gas will replace the atmosphere inside the furnace. One involves its complete mixing with the original atmosphere, and purging results from the gradual reduction of the original atmosphere throughout the furnace as gas is exhausted. The other mechanism is referred to as the *plug effect*. In this effect gas entering the furnace at the bottom rises toward the outlet at the top, pushing the original atmosphere before it in plug-like flow.

Actually, a mechanism which is a combination of both of these flow regimes takes place in large furnaces. The theoretical curves for each of these modes of flow are functions of the holding time, θ, within the furnace. This holding time is the ratio of the furnace volume to the volume of gas flowing through the furnace. For plug-type flow the following equation holds:

$$1 - \frac{C_{ave}}{C_i} = \frac{t}{\theta} \qquad [2]$$

where: C_i is the concentration of krypton or initial furnace atmosphere, C_{ave} is the average concentration of the krypton after the elapse of time t, and θ is the furnace volume divided by the volume rate of flow of purge gas.

For perfect mixing of the gas within the furnace, the concentration after time t has elapsed is given by:

$$C = C_i\, e^{-t/\theta} \qquad [3]$$

The theoretical curves for the furnace being used as the example here are shown in Fig. 1. Curve 1 is the theoretical curve for complete mixing, while Curve 2 is the theoretical curve for plug-type flow. The actual curve, as determined by the krypton tracer technique, should lie somewhere between these two theoretical curves.

When the radioactive krypton had reached distribution equilibrium inside the furnace (as indicated by a uniform decrease in the count rate), its concentration was arbitrarily chosen to represent the original atmosphere inside the furnace which was being purged. The succeeding count rates then gave a direct representation of the amount of the original atmosphere remaining in the furnace after any length of time. The results of an actual test are shown as Curve 3 of Fig. 1. This particular curve can be used to determine the length of time required to purge the furnace to any particular concentration of the original atmosphere.

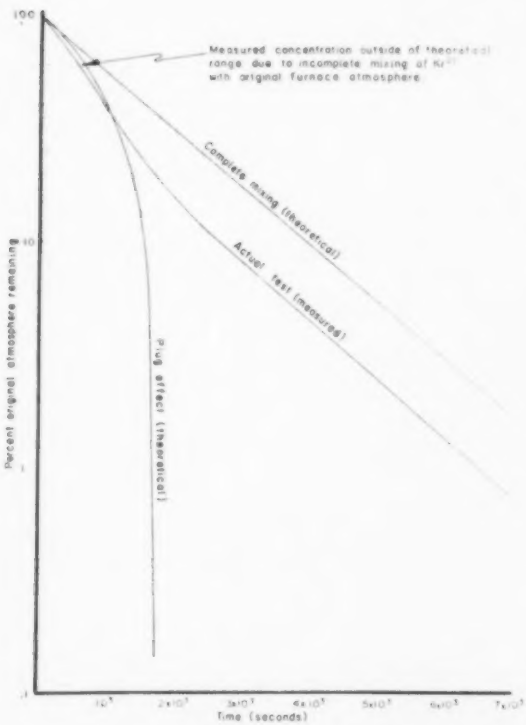

Fig. 1—Theoretical and actual purging curves for 750-cu-ft furnace.

Krypton characteristics

Krypton 85 is a fission product of uranium. Its principal isomer emits a 0.695 Mev beta particle upon disintegration and has a 9.4 year half-life. Being a noble gas, krypton is chemically inert and in no way affects the operation of the furnace or the chemical reactions taking place inside it. For this reason it is particularly adapted for use as a tracer in air-flow studies in high-temperature atmospheres.

Since krypton is not used in body metabolism, the radiation dose received from inhalation of the gas is negligible compared to the external hazard of total body immersion in the gas. Typical amounts of krypton used in a run on a furnace would be less than 100 millicuries. Using only this amount of krypton, it would be virtually impossible to confine it in such a way as to exceed the maximum permissible concentration of the gas in a working atmosphere and so be dangerous to man. In addition, krypton is physically non-toxic in any concentration.

Since Kr^{85} is convenient to handle from a health physics viewpoint . . . has a good half-life and beta particle energy . . . is very economical . . . and can be readily procured in stock quantities, it is surprising that it has not gained more widespread recognition as a radioactive tracer gas in industry.

Phases and Processes

HIGHLIGHTING CURRENT DEVELOPMENTS IN METALS

Nuclear Metallurgy

by H. H. Chiswik of Argonne National Laboratory

NUCLEAR Metallurgy played a significant role in the technical program of the National Metal Congress held in Chicago, Nov. 2-6. Two symposia were held: one on *Effects of Irradiation on Fuel and Fuel Elements*, sponsored by the Nuclear Metallurgy Committee of the Institute of Metals Division of The Metallurgical Society, and the other on *The Rare-Earths and Related Metals*, sponsored jointly by the American Society for Metals and the US Atomic Energy Commission. In addition, one session of the regular ASM program was devoted exclusively to nuclear metals, with six papers presented on the physical metallurgy of uranium and zirconium and their alloys.

The symposium on irradiation effects stressed the evaluation of metallurgical properties and variables that effect the useful life of fuel elements in a reactor. This is a very timely subject in that the inability to reach full reactivity lifetime in fuel elements continues to hamper the attainment of economically competitive nuclear power. Receiving considerable attention in this respect was the phenomenon of *swelling*, which is attributed to agglomeration of inert gas atoms in the fuel by nuclear reactions. Fourteen papers were presented in two sessions, one devoted to metallic fuels, the other to ceramic fuels. The metallic materials discussed included uranium, uranium alloys with columbium and zirconium, and uranium-plutonium-*fissium* alloys as potential fast-reactor fuels. Of the ceramic materials, attention was centered on uranium dioxide, with considerable interest on uranium-carbide.

J. A. Brinkman, Atomics International, keynoted the symposium with a theoretical discussion of our present state of knowledge and concepts of the principal lattice defects produced during irradiation—vacancies, interstitials, and *displacement spikes*— and suggested mechanisms by which these defects manage to induce anisotropic growth, swelling, and phase-reversals. In uranium metal, the author calculates that the fission fragments from a single fission event produce some 54,000 displaced atoms. The phase-reversal effect in U-Mo and U-Cb alloys is ascribed to the action of *displacement spikes*, some 1300 of which are produced in a single fission event. Growth is thought to result from the combined effects of displacement spikes, interstitials, and vacancies. Although some of the experimental data are in agreement with the proposed model for the generation and interaction of these defects, the author regards the model as qualitative and suggests that it should be used for "order of magnitude" estimates only. This he couples with a plea for more basic experiments to determine more accurately the parameters for which simplifying assumptions are made in the theoretical calculations.

The experimental aspects of swelling and various interpretations of its causes were discussed in two papers by A. T. Churchman, Berkeley Laboratories, Central Electricity Generating Board, London, and by R. S. Barnes, of the UK Atomic Energy Research Establishment at Harwell. Experimental evidence is cited to indicate that even at low temperatures and in the early stages of irradiation, the gas atoms precipitate in an array of bubbles of about 200 to 400 A in diam on almost uniformly spaced nucleation sites about ½ micron apart, so as to produce something like 10^{12} such bubbles per cu cm. In this stage, however, the gas is retained by surface tension forces and the overall volume change is small. At higher temperatures, some of these bubbles break away from the surface tension restraint and agglomerate into larger bubbles to cause macroscopic swelling and cracking. The precise mechanism of this agglomeration process is not yet too well understood.

Effects of dimensional instability, due to anisotropic growth and swelling, were discussed by T. T. Claudson and co-workers from Hanford in a paper on the *Operational Performance of Bonded and Unbonded Uranium Fuel Rods*. A striking example of swelling was described in which a ⅜-in. diam cored axial hole in a uranium cylinder had completely closed up after irradiations to 0.1 atomic pct burnup at about 800°C. The material that filled the hole by swelling showed extensive porosity, with a decreasing density toward the central axis. Other examples of dimensional instability cited included radial extension and longitudinal shrinkage in the early stages of irradiation, length increases in the later stages, and macrocracking.

Fuel elements for fast power-breeders were discussed by J. A. Horak and J. H. Kittel from Argonne. The materials of interest in connection with the Experimental Breeder Reactor-II being developed and built by ANL to demonstrate the breeder concept and the pyrometallurgical reprocessing of spent fuel are the so-called *fission* alloys; these are uranium-base alloys containing the fission-product elements Zr, Mo, Ru, Rh, and Pd in fixed ratios determined by the reprocessing cycle, with a total content of about 5 to 10 wt pct. The alloys were reported to have good swelling resistance at temperatures below 700°C. Additions of 10 to 20 wt pct plutonium, however, lowered the temperature at which swelling begins to about 400° to 450°C. Work is in progress to raise the swelling temperature by alloying; zirconium additions appear promising.

W. K. Barney, Knolls Atomic Power Lab, discussed advantages of UO_2 from the standpoint of improved dimensional stability. Under examination were two types of fuel elements: UO_2 particles dispersed in stainless steel matrix, and low bulk density (60 pct) UO_2 powders contained in stainless steel tubes. In the former type fuel element, porosity is developed in the UO_2 particles and some cracking may occur within them, but no swelling results in the individual particles. A suggested explanation is that appreciable quantities of the fission gases are retained in the UO_2 lattice. In the loosely-packed-type elements, the powders sinter to a solid mass in the early stages of irradiation, and continued irradiation produces pores and swelling within the material until restrained by the container. No external overall swelling was noted in either type element. Along similar lines, J. L. Bates and W. E. Roake, Hanford Atomic Products Operation, described the irradiation behavior of packed UO_2-PuO_2 powder mixtures in Zircaloy tubes. The powder sinters and is relocated axially and radially by densification occurring in the early stages of sintering, forming hollow cores surrounded by radially-oriented, columnar grains. The authors suggest that the columnar grain structure is formed by vapor phase dendritic deposition.

Shaping and Forming

by D. S. Fields, Jr. of Alcoa Research Laboratories

THE bulk of published literature on deep drawing is unwieldy because of the large number of variables that may be introduced into deep drawing operations. It is usually difficult to utilize either theoretical or experimental results because of dissimilarities of equipment and operating techniques among installations.

Swift Cup-Forming Test

A set of specifications for a standardized drawability test has been developed under the sponsorship of the Sheet Metal Working Committee of the British Iron and Steel Research Assn., that incorporates many of the features developed by Professor H. W. Swift[1] in his work at the University of Sheffield. The specifications call for the deep drawing of cylindrical cups to determine the maximum diameter of a blank that may be consistently formed without failure. A 32 or 50 mm cup is drawn, depending upon sheet thickness. Results are expressed in terms of the Limiting Drawing Ratio (LDR) of the blank to punch diameters. "Parts of the test, which are at present specified, are the dimensions of blanks and tools, the dimensional tolerances and finish of the tools, the properties and method of application of the lubricant, the method of preparation of the test specimen and the conditions of testing."[2]

In setting up the specifications for the Swift Cup-Forming Test, it was intended that results should correlate with press-room performance, so as to afford the laboratory a reproducible, simulated test to use as a basis for drawability investigations.

The Swift Cup-Forming Test has not been widely accepted in this Country as yet, although some companies use similar cupping tests of their own design. Since a complete Swift-type evaluation may require the preparation and testing of several dozen blanks, it is hardly practical for plant quality-control. It is more likely that the test will remain primarily a laboratory tool used to assess other more simple and direct formability tests.

Drawability

Tests over hemispherical punches[3] indicate a steady decline in drawability with increasing amounts of prior cold work in the sheet. On the other hand, cold rolling of the aluminum alloy investigated in amounts up to approximately the ¼ *hard* temper resulted in an improvement of drawability over a flat-bottomed punch. Naturally any simple laboratory test that correlates with performance in the first case cannot correlate with the other. Such anomalies as this have brought about recognition of the fundamental difference between a relatively pure drawing operation and sheet working in which the metal is subjected primarily to stretching.

The present concept of the pure drawing operation is that drawability is governed by a delicate balance between drawing force and the strength of the metal in the lower cup sidewall. Any condition, such as inadequate lubrication, excessive holddown pressure, or improper tool design or surface finish will tend to raise the draw force, perhaps to a level exceeding the sidewall strength. With regard to sheet properties, it has been contended that variations in the strain-hardening characteristics of the material can lead to a change in the relative values of wall strength and maximum draw force, and thus markedly influence drawability. The improved drawability, cited above, obtained by cold rolling the aluminum alloy has been attributed to the enhanced strength near the bottom of the cup. The actual details of the processes leading to failure in drawing have been analyzed by Swift[1] in terms of the thinning that takes place as the sheet is bent and unbent over the die radius during early stages of the draw.

A provocative paper was presented by Whiteley[3] at the National Metal Show. Theoretical and experimental evidence was presented indicating that variations in formability from one alloy to another are due only to the relative degrees of directionality in their mechanical properties. This directionality is measured as the ratio of width to thickness strains in sheet tensile specimens. The greater the ratio, the more this directionality enhances the resistance of the cup sidewalls to thinning under the drawing load. It is stated that some reduction in drawing force also results from large values of the ratio, but that the predominant effect is upon the sidewalls. The surprising fact is that, on such a basis alone, a correlation may be obtained for drawing behavior of aluminum, carbon steel, and stainless steel, as well as among various heats of a given alloy. It has generally been assumed that the variations in drawability observed among the several alloy systems should in some way be related to the marked differences in their strain hardening characteristics; however, Whiteley asserts that measurements of strain hardening exponent n—where the stress-strain curves are represented by power law functions—do not show a significant correlation with his cupping test results. He further indicates that this result is consistent with his theoretical analysis, which shows no dependence upon n.

Stretch Forming

Varied claims of improved formability have been made for metals and alloys shaped by explosive loading. Explosive forming, as frequently discussed in the literature[4, 5] and during an ASM Panel on Explosive Forming at the recent Metal Congress, has found its greatest use for operations of the stretch forming variety. Pressure is transmitted through air or water to flat or cylindrical specimens by an explosive, high-pressure shock wave.

A clearcut economic advantage of explosive working is that the inertia effects in the sample under such rates of loading allow the elimination of one or both of the forming dies used to fabricate the part conventionally.

Often stated, but less well documented, is the beneficial effect of explosive forming rates on ductility and formability. It is hard to tell whether the improvements result from the dynamic effects of the explosive loading or from the lack of frictional restraints between the work piece and the die.

The hydraulic bulge test offers a set of conditions resembling those of many explosive forming operations. Experimental and theoretical studies of the bulge test have been made both in the US and the UK. Practical use of the test to simulate behavior of sheet during stretch-type forming operations has also been made.[6] It may be expected that further utilization will be made of the test in assessing the actual conditions governing the flow of metal during explosive, as well as conventional, stretch forming.

References

[1] H. W Swift: The Mechanism of a Simple Deep Drawing Operation. *Sheet Metal Industries*, v. 31, 1954 p. 817. This represents one of a number of descriptions of the deep drawing research carried out at the University of Sheffield.

[2] O. H. Kemmis: The Assessment of the Drawing and Forming Qualities of Sheet Metal by the Swift Cup-Forming Test. *Sheet Metal Industries*, v. 34, 1957, p. 203, 251.

[3] R. L. Whiteley: The Importance of Directionality in Drawing Quality Sheet Steel, *Transactions*, American Society for Metals, 1959 Preprint No. 174.

[4] *Metal Progress*, v. 76, no. 5, Nov. 1959, p. 140; a digest of current progress in explosive forming by an aircraft company.

[5] *Steel*, v. 145, no. 21, Nov. 23, 1959, p. 74; a digest of current progress in explosive forming by an explosives manufacturer.

[6] W. N. Lambert, E. S. Madrzyk, and F. E. Gibson: A New Method for Determining the Drawing Quality of a Sheet by Use of the Hydraulic Bulge Tester, presented at the Fall 1959 Meeting of The Metallurgical Society, AIME. (Appearing in a future issue of JOURNAL OF METALS.)

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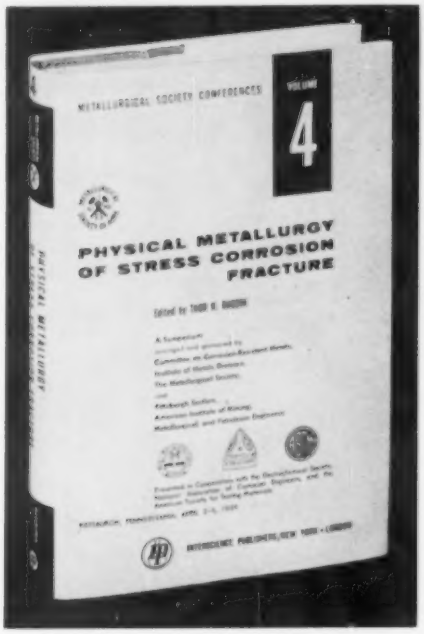

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NEWS OF YOUR PROFESSION

Southwest Conference Coming Up Apr. 21-23!

The AIME Southwest Metals and Minerals Conference coming up Apr. 21-23 at the Ambassador Hotel, Los Angeles, promises metallurgists some attractive papers and topics.

From 9:30 am to noon on the opening day, an All Participants Session will be held in the East and West Venetian Rooms. At that time Abraham Hurlich, Convair Astronautics will comment on the film *Materials for Booster Vehicles* as it is shown. Papers scheduled are *Energy Sources in Space*, by A. M. Zarem of Electro-Optical Systems; *and Borated Concrete—New Shielding Applications*, by John de Arrieto of Atomics International.

Immediately following will be the All Participants Luncheon, addressed by AIME President Joseph L. Gillson. Dr. Gillson's subject will be *Industrial Minerals in the Southwest.*

Friday, Apr. 22nd, will be the occasion for the Conference's two metals sessions. The first is on Beryllium Metallurgy and meets in the West Venetian Room from 9 am to 12 on that date. Seven beryllium papers will be given, including *Recent Progress in Beryllium Metallurgy* by W. W. Beaver of Brush Beryllium Co., *Ductile Beryllium Alloys* by S. R. Maloof of Avco Corp., *The Physical Metallurgy of Beryllium* by J. P. Denny of Beryllium Corp., and *Beryllium Metal* by E. Kaufman and S. H. Gelles of Nuclear Metals Inc.

Materials for Space Vehicles is the theme of the second metals session, meeting from 2 pm to 5 pm in the West Venetian Room. L. D. Jaffe of the Jet Propulsion Laboratory, California Institute of Technology, is presenting a paper on *Effect of Space Environment on Space Materials.* Also scheduled are *Material Problems in Space Vehicle Engine Development* by Robert Boundy also of Jet Propulsion Laboratory, *Material Problems in Temperature Control of Space Vehicles* by Robert Lipkis of Space Technology Laboratories Inc., and *Material Problems and Experiments in Space* by E. C. Burke of the Missile Systems div. of Lockheed Aircraft Co.

See p. 240 for a related story.

Pacific Northwest Metals Program

The tentative metals session program for the Pacific Northwest Metals and Minerals Conference has been released. Harry Czyzewski, chairman of the metals part of the Conference, announces that two days —Apr. 28-29—will be devoted to metallurgy. The Conference itself runs through Apr. 30th.

Thursday morning, Apr. 28th, will deal with extractive metallurgy. Theme of the session is Process Metallurgy. Four papers are scheduled: *The Current Status of the Direct Reduction of Iron Ore* by L. H. Lownie, Jr. of Battelle Memorial Institute, *Recent Developments in the Strategic-Udy Process* by Murray C. Udy of Strategic-Udy Processes Inc., *Production of Ferronickel at Riddle, Ore.* by Emmons Coleman and D. N. Vedensky of The Hanna Mining Co., and *Recovering Alumina from Ferruginous Bauxite* by Lloyd H. Banning of US Bureau of Mines, Albany, Ore.

In the afternoon of Apr. 28th, iron and steel will come in for discussion in terms of New Fabrication Techniques. Three papers are scheduled: *Explosive Impact Hardening of Manganese Steel* by S. S. Jenkins, Jr. of E. I. duPont de Nemours and Co., *Recent Studies in the Explosive Working of Metals* by John Pearson of US Naval Ordnance Test Station, China Lake, Calif., and *Latest Developments in the Chemical Milling Field* by James D. Barton of Turco Products Div., Wilmington, Calif.

Friday morning, the 29th, deals with physical metallurgy. Melting and Casting of Exotic Metals is the theme of this session. Four papers are slated: *The Production of Refractory Metals Using the Electron-Beam Technique*, by E. F. Baroch, Wah Chang Corp.; *Dingot Quality Vacuum Remelted Uranium Metals from Ceramic-Coated Graphite Crucibles*, by J. C. Tverberg, General Electric Co., Hanford, Wash; *A Laboratory Casting Furnace for High Melting Point Metals*, by P. G. Clites and E. D. Calvert, US Bureau of Mines, Albany, Ore; and *A Liquid Cooling System for Consumable Electrode-Arc Furnaces*, by D. E. Cooper and E. Don Dilling, Titanium Metals Corp.

ORGANIZERS—Pictured above are two of the principals involved in planning the Pacific Northwest Regional Conference, to be held at the Sheraton Hotel in Portland, Ore., Apr. 28-30. The newly-constructed hotel serves as a backdrop as General Chairman Hollis M. Doyle (left), offers an idea to John R. Anderson, Co-chairman.

The afternoon of Friday, the 29th, will again deal with iron and steel. Heat Resistant Alloys is the theme of this session. Three papers are scheduled: *Classification and Application of Heat-Resistant Alloys*, by Ernest Schoefer, Alloy Castings Institute; *Heat-Resistant Alloy Properties*, by Dean Burgan, Electric Steel Foundry Co.; and *Fabrication of Heat-Resistant Alloys*, by M. D. Bellware, International Nickel Co.

NOTICE TO AUTHORS

Make sure that manuscripts are typed double-spaced before submitting them to the JOURNAL OF METALS. Failure to do so results in retyping, chance of error, and needless delay. To facilitate matters, submit papers in duplicate and enclose illustrative material such as drawings and glossy photos at the same time. Such illustrations should be suitable for reproduction.

Set LA Program for Acid Converter and Basic Oxygen Group

The complete program for the AIME Acid Converter and Basic Oxygen Steel Committee meeting April 20-22, at the Ambassador Hotel, Los Angeles, is printed below.

The Committee's Annual Meeting is this year being held in conjunction with the Southwest Metals and Minerals Conference and a Western section, NOHC, meeting. A Manned Space Stations Symposium, sponsored by the National Aeronautics and Space Administration, and others, will also meet at the same time and place. The Acid Converter and Basic Oxygen Steel Committee program is as follows:

APRIL 20

9:00 am—Bus transportation from the Ambassador Hotel to Kaiser Steel Corp., Fontana, Calif.

11:00 am-1:00 pm—Visit basic oxygen steelmaking plant, Kaiser Steel.

1:00 pm-3:00 pm—Lunch at Fontana.

3:00 pm-5:00 pm—Bus from Fontana to the Ambassador Hotel.

7:00 pm-8:00 pm—Dinner with Western section, AIME, at Ambassador Hotel.

8:00 pm-9:30 pm—J. E. Tredennick, Kaiser Steel Corp., *Basic Oxygen Steelmaking.*

APRIL 21

10:00 am-12:15 pm—Round table discussion of the Acid Converter Steelmaking Process, Chairman, A. B. Wilder, National Tube div, U .S. Steel Corp. Grove Lounge, Ambassador Hotel.

12:15 pm-2:00 pm—Southwest Metals and Minerals Conference Luncheon, Ambassador Hotel.

2:00 pm-4:30 pm—Continuation of round table discussion of the Basic Oxygen Steelmaking Process.

APRIL 22

9:00 am-12:15 pm—Technical Program of AIME Acid Converter and Basic Oxygen Steel Committee, Grove Lounge, Ambassador Hotel Chairman, R. C. Madden, Algoma Steel Corp., Sault Ste. Marie, Ontario, Canada; Vice Chairman, J. F. Pollack, Jones & Laughlin Steel Corp., Pittsburgh.

9:00 am-10 am—*Investigation of Bessemer Converter Smoke Control*, by A. R. Orban and J. D. Hummell, Battelle Memorial Institute.

10:00 am-11:00 am—*The Acid Bessemer Oxygen-Steel Process*, by G. M. Yocom, Wheeling Steel Corp., Steubenville, Ohio.

11:00 am-12:15 pm—*The Physical Chemsitry of Oxgen Steelmaking*, by D. L. McBride, director of metallurgical process development, U. S. Steel Corp., Pittsburgh.

12:15 pm-2:00 pm—Southwest Metals and Minerals Conference Luncheon, Ambassador Hotel.

Additional Information

For further information, contact A. B. Wilder, Chairman, AIME Acid Converter and Basic Oxygen Steel Committee Meeting, National Tube div, U. S. Steel Corp., 525 William Penn Place, Pittsburgh 30, Pa. Reservations for transportation from Los Angeles to Fontana must be made with A. B. Wilder at least one week in advance of the meeting. Reservations at the Ambassador Hotel should be made immediately, indicating you will attend the Committee meeting.

Herbert W. Graham Given Basic Oxygen Committee's First Award

Herbert W. Graham, retired vice president and director of technology, Jones & Laughlin Steel Corp., was the recipient of the first of a newly-established award granted by the Acid Converter and Basic Oxygen Committee of the Iron and Steel Division. Presentation was made during the Committee's luncheon at the Annual Meeting, Feb. 18th. A "major contribution" to acid converter or basic oxygen practice is the basis for the award. It was Mr. Graham who conceived and developed the high-sulfur, intermediate-maganese steels which later became the X1300 series. He originated the use of air-quenched intermediate-maganese steel in a tubular joint of original character, and developed the use of intermediate manganese steel for tank armor during World War II.

Mr. Graham has also conducted research and written on the following subjects: the machinability of free-cutting steels . . . embrittlement of steel . . . and the bessemer process.

The award winner joined J & L on his 23rd birthday in 1914, and remained with them until his 1956 retirement. His only break in service was during World War II, when he was on loan to the Government. Then he was steel consultant to Office of Production Management and the War Production Board.

In 1947 Mr. Graham delivered the AIME's Howe Memorial Lecture on the subject: *Factors Which Determine Iron and Steel Mcking Processes.*

A J&L research laboratory, named the Graham Laboratory, was dedicated to his services in 1955.

More recently, he assumed the presidency of TEAM, Inc., a research consulting organization made up of retired executives from industry.

EDUCATION

(Continued from page 172)

to coat materials with coherent dissimilar metal oxide films.

Industry Irradiation Accepted

► Battelle Memorial Institute is now accepting a "larger number of requests" from industry for the irradiation of specimens that will be used in research studies conducted by individual companies. H. R. Nelson, manager of nuclear research activities at the Institute, made the announcement.

The power level of the Battelle research reactor was doubled last year, raising its normal operating level to 2000 kw. The reactor can accommodate a variety of specimens in its six 8-in. diam beam tubes and in its thermal column with a 3½-ft diam vertical and 5-ft square horizontal entrance.

Research Scope

► More than 10,000 research projects are now underway in 118 leading engineering colleges across the Nation, according to a report by the Engineering College Research Council (ECRC) of the American Society for Engineering Education. Expenditures on these research activities will total more than $112,000,000, during 1960.

The 1959 survey, entitled, *ECRC Research Review*, gives complete titles for all projects underway in schools which hold ECRC membership. In addition, numbers of research personnel at each institution are listed and research policies summarized. There is a complete index of research project subjects to help locate activities in similar fields at different institutions.

Copies of the Review are available at $2 each from W. Leighton Collins, Secretary, American Society for Engineering Education, University of Illinois, Urbana, Ill.

Films

► *Cast Metals and You* is the title of a film just released by the Education Division of the American Foundrymen's Society.

The film depicts the evolution of foundry practice from a personal art to its development as a basic industry. Film shots show plant training programs, the skills of the pattern maker, design clinics, and laboratory facilities of foundries and leading engineering colleges.

The film is available on free rental (except for transport charges) to educational institutions and civic groups. Others may obtain it for a $10 rental fee, plus shipping costs. Requests should be directed to American Foundrymen's Society, Golf and Wolf Roads, Des Plaines, Ill.

PERSONALS

(Continued from page 188)

Walter R. Meyer, president of Enthone, Inc., has been issued a patent for an electrolytic alkaline descaling and derusting process. Enthone is a wholly-owned subsidiary of American Smelting & Refining Co.

Maurice Nelles has stepped into the new post of vice president-engineering, created by American Electronics, Inc., At this Los Angeles-based plant, Dr. Nelles will direct engineering planning for the corporation's nine divisions. Before joining American Electronics, he was associated with the Crane Co., Chicago.

Walter A. Dean is now assistant director of research for the Aluminum Co. of America. He succeeds **William T. Ennor,** who recently retired from the post after 35 years with Alcoa. Before his appointment, Dr. Dean was development metallurgist for the Company's metallurgical div. Among other activities, he is chairman of the panel on forgings and extrusions of the Materials Advisory Board, National Academy of Sciences.

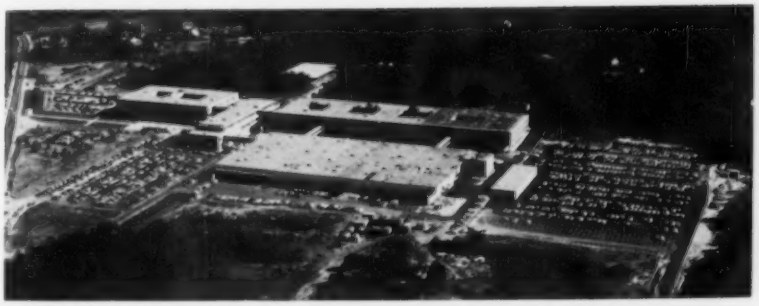
The retired Mr. Ennor is probably best known for the invention and perfection of the continuous ingot casting *DC* process now used throughout the world for aluminum and other metals.

James F. Schumar has been appointed chairman of the Metallurgy Dept. at John Jay Hopkins Laboratory of General Dynamics Corp.'s General Atomic div. Mr. Schumar will join the San Diego, Calif., based laboratory from his post in the Metallurgy Dept. of Argonne National Laboratory. On leaving Argonne, he was Associate Director of the Dept. A leading metallurgist in nuclear technology, Mr. Schumar's work on uranium fabrication methods lead to construction of the Nation's first atomic reactors.

Thomas K. Graham is now metallurgical manager of the Anaconda Co. He had been asst. metallurgical manager since 1958, and before that was manager of the Raritan Copper works of International Smelting and Refining Co.

George F. Ewald has been appointed manager of the Michigan works, Revere Copper and Brass, Inc. He has been with Revere since 1934, and has served as a methods man, metallurgical engineer, and supervisor there.

George L. Flint has been named Western District sales manager for Mallory-Sharon Metals Corp. He had been manager of the Company's Southern District since 1956.



New England Meeting to Visit Avco R&D Center

The Avco Research and Advanced Development Center will be visited by registrants for the 14th New England Regional Conference, meeting at the Hotel Statler in Boston May 26-27. The Wilmington, Mass., facility is located 15 mi northwest of Boston.

As to vital statistics for those who anticipate making the plant trip, the major research and development work done there is in support of this Country's long-range ballistic missile program. More than 2200 scientists, engineers, and other personnel are engaged in re-entry programs at the Center. In terms of physical properties, the buildings cover 16 acres, with a floor area exceeding 465,000 sq ft.

Spelling out the programs in high-temperature materials, a comprehensive beryllium program includes physical properties studies, advanced methods of joining, and new techniques of purifying. Molybdenum work is in the area of joining, fabrication, development of oxidation-resistant coatings, and improvement room temperature ductility.

Projects in powder metallurgy and ceramics range from alloy and fabrication process development of unique metals to development of new metal-plastic-ceramic composites for high-temperature applications. The brazing of honeycomb structures is also being undertaken utilizing columbium, tantalum, and molybdenum.

The physical metallurgy lab houses an electron microscope, electron and X-ray diffraction units, and X-ray microscope. The chemical analysis laboratory is stocked with X-ray spectrograph and fluorescence units, vacuum fusion apparatus, hypersensitive balance equipment, and radioactive tracers. Metals processing facilities include a development-type rolling mill, vacuum furnaces, heat-treating equipment, swaging and drawing machines, and a developmental electroplating lab.

Physical testing is done with specially-designed, high-heat-rate, creep equipment and standard creep test units; tensile, torsion, fatigue, impact, and transverse rupture testing equipment is also available. New concepts of nondestructive testing are under development in ultrasonics, radiography, eddy current, and penetrant testing, including several pure research investigations delving into ceramics and plastics. The powder metallurgy and ceramics section has a custom-built 400-ton powder press, hydrostatic presses, specially-designed ceramic kilns, furnaces, and powdered material preparation equipment. A liquid-metals laboratory is operating with facilities for handling, purifying, and experimenting with sodium and lithium.

Besides the plant trip, the two-day meeting will incorporate three technical sessions. Session topics will be high-speed forming, extrusion, and special forming processes.

FOR THE FIRST TIME

You can have in one reference book the most up-to-date information on the many new developments in the metallurgy of copper, nickel, and cobalt. The book is the PROCEEDINGS of the INTERNATIONAL SYMPOSIUM ON THE EXTRACTIVE METALLURGY OF COPPER, NICKEL, AND COBALT. Based on the Symposium presented at the 1960 AIME Annual Meeting, it will be published later this year. Order your copy now.

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The Secretary
The Metallurgical Society
of AIME
29 West 39 Street
New York 18, N. Y.

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☐ AIME member

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AIME

BOARD OF DIRECTORS

Recent actions taken by the Institute Board of Directors.

► Wilfred Sykes has been elected to Honorary Membership. The citation conferred by the Honorary Memberships Committee reads: "For distinguished service to the steel industry, particularly as a pioneer in the development of electrical equipment for steel mills . . . "

Honorary membership has also been conferred on John Meston Lovejoy, H. Dewitt Smith, and William E. Wrather. Mr. Lovejoy's citation reads, in part: "For distinguished service to the Institute, for his outstanding contributions in furthering the professional status of petroleum engineers. Mr. Smith was named as "a mining engineer whose life and achievements have brought new luster to that great calling . . ." Mr. Wrather's citation reads: "In recognition of his outstanding contributions to the profession as pioneer petroleum geologist and discoverer of the Desdemona Field . . ."

► Pittsburgh section has been named one of the winners in AIME's annual membership application contest.

Based on the submission of the largest number of applications in relation to other Sections within its group, Pittsburgh has won a gavel as tops in Group E.

► The following members have been elected to Senior Membership:

Beck, E. L.
Culver, Harold E.
Davies, Fred A.
Dorr, John V. N.
Fetherston, John T.
Garber, C. Y.
Huddle, Charles R.
Marsh, Harry M.
Mitchell, Walter L.
Ong, J. N.
Rains, L. F.
Tremoureux, R. E.

Design Engineering Seminar June 12-17

A seminar in design engineering is scheduled for the Pennsylvania State University campus June 12-17. The purpose of the seminar is to stimulate imaginative and creative thought in design engineering, and the development of methods for application to projects or systems.

Inquiries about the seminar should be addressed to Maurice S. Gjesdahl, Prof. of Mechanical Engineering, The Pennsylvania State University, University Park, Pa.

Second Conference on Mechanical Working Draws Record Number

Flat Rolled Products: Semi-Finished and Finished was the subject of the Second Mechanical Working Conference held at Hotel Del Prado, Chicago, before an audience of 276. Seven technical papers were presented, with many opportunities offered for discussions.

First under discussion was *Hot Machine Scarfing of Semi-Finished Carbon Steels*, a paper authored by L. J. Trilli, Open Hearth and Blooming Mill div., Inland Steel Co. Mr. Trilli described the increased applications of machine scarfing to remove surface defects. He concluded that maximum efficiency could be obtained when defects are shallow, and that most defects can be removed with a standard hot scarfing practice. For cuts deeper than 1/32 in., more defects can be removed but at increased cost. Hot scarfing gives added flexibility in scheduling use of equipment.

W. W. Brown, Process Metallurgist, U. S. Steel Corp., Pittsburgh, spoke on the *Selection of Ingot and Slab Sizes for the Modern Strip Mill*. In the paper he described the use of computers in utilizing equipment in the most efficient manner.

A paper on *Fundamental Aspects of Scale on Hot Rolled Strip*, by S. Garber, British Iron and Steel Research Association, Sheffield, England, was presented by J. F. Jarrell, Steel Co. of Canada Ltd. The paper noted that when scale is removed by running through acid baths at elevated temperatures, removal is not uniform. The paper also dealt with the variations in depth of three layers of iron oxide (wüstite, magnetite, and hematite), and their adhesive qualities.

Serving as chairmen of the morning session were C. R. Taylor, Armco Steel Corp., Middletown, Ohio; and J. McCarthy, Jones & Laughlin Steel Corp., Aliquippa, Pa.

After a luncheon interval, the afternoon session began with a paper on *Temper Rolling and Its Effect on Stretcher Strain Sensitivity*, presented by I. I. Bessen, Jones & Laughlin, Pittsburgh. Co-author of the paper was E. J. Paliwoda, a J & L co-workers. Mr. Bessen described the commercial method of temper rolling to reduce yield point elongation.

Unitized Automobiles was the subject of a paper by Carl Cenzer, American Motors Corp., Detroit. Single unit construction which eliminates bolting and welding has resulted in a more effective means of absorbing initial impacts, most of which occur at the front of the vehicle, he explained.

Two papers were presented on the *Processing and Properties of Magnetic Materials*. R. H. Trapp, Westinghouse Electric Corp., discussed fundamentals of processing magnetic materials. He listed the principles involved in the development of these materials and the effect of impurities. P. H. Estes, General Electric Co., described the processing of materials after they arrive in the customer's plant, and listed major breakthroughs of the last decade.

Chairmen at the afternoon session were A. F. Forrest, Republic Steel Corp., Cleveland, and P. J. Ladomer, Great Lakes Steel Co., Detroit.

A special feature of the Conference was the luncheon talk by Thomas Collins, Assistant Managing Editor, *Chicago Daily News*. Mr. Collins talked on *How Business and Professional Men Must Prepare for Retirement*. He counselled individuals near retirement not to take their pension and pull up stakes or to completely stop work when they get their pension. Mr. Collins challenged his listeners to write a book, compose music, or invent something after age 65.

Chairman of the Conference was Ralph D. Hindson, Steel Co. of Canada Ltd., C. F. Schrader, Inland Steel Co., present vice chairman, will become the new chairman of the Mechanical Working Committee. P. H. Smith, La Salle Steel Co., Chicago, goes from secretary-treasurer to vice chairman. T. E. Dancy, Jones & Laughlin, Pittsburgh, is the incoming secretary-treasurer.

The papers and discussion presented at the Mechancial Working Conference will be published by Interscience Publishers as a Proceedings volume in the series of **Metallurgical Society Conferences.**

Zinc Institute Meeting in St. Louis

Thursday and Friday, Apr. 7-8, are the dates for the 42nd Annual Meeting of the American Zinc Institute. Sessions will meet at the combined Chase-Park Plaza Hotels in St. Louis.

Reports on developments in foreign trade and the development of world lead and zinc markets are scheduled for Thursday morning. The Lead Industries Association and the Galvanizers Committee of the steel industry are cooperating in the reports. Thursday afternoon will be given over to a report on the Zinc Institute's expanded research program, plus a report on the use of galvanized sheet for prefabricated buildings.

Of more metallurgical interest is the final session on Friday morning, when trends in zinc oxide and brass, die casting, and rolled zinc will be set forth. A discussion of mining economics will also take place.

Symposia, Plant Trips Listed For Powder Metallurgy Meeting

The International Powder Metallurgy Conference meeting in New York during June will comprise a full week of technical sessions and plant tours. The Conference—the first of its kind to be held in the US by non-profit organizations—will be at the Hotel Biltmore from June 13 to 17.

Technical sessions will begin at 9 o'clock Monday morning, the 13th. This first day will be devoted to a discussion of Powder Metallurgy Fundamentals and Theory.

From this basis, the Conference will launch into a Symposium on Dispersion Strengthening at 9 am Tuesday, the 14th. At 2 pm that afternoon a Symposium on Powder Metallurgy Techniques and Methods will be staged. Tuesday evening will be given over to a banquet, with George A. Roberts, President, Metal Powder Industries Federation, presiding.

Beginning at 9 am on Wednesday, the 15th, the scene will change to an all-day Symposium on Powder Metallurgy Alloys, Materials, and Applications. Presentation of technical papers will officially end at 5:30 pm that day.

Thursday and Friday, June 16 and 17, will be given over to plant trips. Five combinations of one-day plant tours covering nine companies have been arranged for registered conference participants. Transportation by chartered bus will be provided, and tour tickets will be available at the Registration Desk on the 19th floor.

Tour No. 1 includes the Hoeganaes Sponge Iron Corp., Riverton, N. J., and the F. J. Stokes Corp., Philadelphia. Hoeganaes Corp. is one of the world's largest producers of iron powder designed for powder metallurgy consumption. F. J. Stokes, is a leading producer of mechanical and hydraulic presses as well as a large variety of vacuum apparatus.

Tour No. 2 is to the Presmet Corp., Worcester, Mass. This medium-sized custom fabricator specializes in sintered structural parts.

Tour No. 3 will take in the Lionel Corp., Irvington, N. J. and the Alan Wood Steel Co., Conshohocken, Pa. Lionel manufactures many products which utilize powder metallurgy parts. Alan Wood has a new iron powder process—the H-Iron Direct Reduction Process. (An article on the process will appear in the April issue of JOURNAL OF METALS).

Tour No. 4 will include Pitney-Bowes, Inc., Stamford, Conn., and the Sintercast div of Chromalloy Corp., Yonkers, N. Y. Pitney-Bowes stresses the production of ferrous materials, including both medium- and high-density parts. Sintercast is specializing in new phases of powder metallurgy, mainly on the developmental and pilot plant level. These include powder rolling and extrusion, machinable carbides, and nuclear control materials.

Tour No. 5 takes in the Adamas Carbide Corp., Kenilworth, N. J., and American Metal Climax, Inc., Carteret, N. J. Adamas Carbide produces its own carbide and cobalt powders, and has complete powder testing facilities. American Metal Climax is one of the major manufacturers of nonferrous powders, principally electrolytic copper powder and atomized tin and solder powders. They will also show their research facilities for metal powders.

The powder metallurgy conference is being jointly sponsored by the Metal Powder Industries Federation (MPIF), and The Metallurgical Society's Institute of Metals Division. Advance registratoin for the Conference is urged. Registration fee for members of the MPIF or AIME is $8; $10 for non-members. Rooms at special rates have also been set aside for those attending the Conference, and early reservation is advised. Regular registration will begin on Sunday afternoon, June 12th. For more details, write the Metal Powder Industries Federation, 60 E. 42nd St., New York 17, N. Y.

Cooperation Asked In Obtaining Manpower Statistics in Census

During the 1960 population census every fourth household will be asked to answer the question:

What kind of work are you doing? In order that the statistics may reflect scientific and engineering manpower as accurately as possible, the Census Bureau has asked that the question be answered completely and precisely. The entry should consist of at least two words in most cases, such as: metallurgical engineer, processing metallurgical engineer, and so on.

See AIME Participation in Nuclear Congress

The program for the 1960 Nuclear Congress spans seven major areas in 57 technical papers. One such area, Materials and Components, will have AIME member, Bruce W. Dunnington of Battelle Memorial Institute, as its Session I chairman. This session will begin at 2:00 pm Apr. 4th, the opening day of the Congress. The Congress, to be housed in the Coliseum in New York, runs through Apr. 7th.

Also participating in the aforenamed session will be Dennis Foley, Alco Inc., speaking on *Problems in Contamination of Water-Cooled Reactors Using Stainless Steel Components;* and D. H. Baker, Jr., M. M. Wong, and R. E. Campbell, US Bureau of Mines, Boulder City, Nev., on *US Bureau of Mines Research on the Fused Salt Electrorefining of Beryllium.*

COLUMBIUM CONFERENCE SITE

SYMPOSIUM SITE—The artist's rendition above depicts Sagamore Hotel, which will be host to the Columbium Metallurgy Symposium June 9-10. The Hotel is situated on Lake George, at Bolton Landing, N.Y. Four sessions on four related topics will comprise the meeting. Topics are mechanical properties . . . fabrication . . . corrosion and oxidation . . . and general physical metallurgy. The Hudson-Mohawk section is its sponsor.

AROUND THE SECTIONS

Connecticut section's first meeting of 1960 was held Wednesday evening, Jan. 13th, at the luxurious Sanford Barn near New Haven. Following dinner, the second in the Section's series on materials research featured a talk by Julius J. Harwood, head of the metallurgy branch, Office of Naval Research. Dr. Harwood discussed the role of government in research, and its effect on metallurgical and materials development.

Nearly 40 members of the Section heard him describe the revolution in the field of materials which has transpired during the past 10 to 15 years. He listed the four significant features of the revolution as follows:

1) Recognition of the importance of materials to technology.
2) The impact of solid state physics on attempts to understand materials.
3) Rapid growth of the discipline now known as materials science; and
4) The impact of government-supported research on our understanding of materials.

Dr. Harwood went on to discuss the organization of the government as it relates to sponsorship of research and development activities, and described numerous examples from the areas in which the government presently sponsors or plans to sponsor research and development activities.

Among those attending the meeting were nine members of the Yale Metallurgcial Society, the AIME student group at Yale University.

Future programs on materials research will deal with activities on university and industry levels.

Southwestern section, NOHC, held an all-day meeting at the Hotel Lennox in St. Louis Feb. 12th. Two technical sessions, a luncheon, cocktail party, and fellowship dinner were jammed into the day. Among the topics under discussion were uptake areas . . . hot patching basic roofs . . . nondestructive testing techniques for preventive maintenance . . . scrap control . . . safety . . . cupola and oxygen process at Acme Steel Co. . . . and Keystone Steel & Wire's new 180-ton open hearth.

Colorado section elected its 1960 officers during the final meeting of 1959 on Dec. 17th. Arthur L. Hill is the newly-elected Section chairman; Alfred G. Hoyl, vice chairman; Walter L. Crow, secretary-treasurer; and Frank E. Briber, Thomas C. Hiestand, Robert R. Wichmann, directors.

San Francisco section heard an explanation of Structural Control of Cordilleran Ore Deposits during its Jan. 13th meeting. Speaker of the evening was Edward Wisser, of the University of California and the consulting firm of Wisser and Cox. The meeting also marked the installation of 1960 officers. Peter Joralemon took over the chairman's reigns, and Evan Just became vice chairman.

The Section's next meeting will be Mar. 12th, when members will join with the ladies auxiliary in staging their annual Dinner Dance at the Mark Hopkins Hotel.

Ohio Valley section's Jan. 14th meeting played host to Preston S. Craig, technical manager of the Redstone div., Thiokol Chemical Corp. The guest speaker's subject was *Weather Forecast of the Future of High-Strength Steels*. Mr. Craig is responsible for the engineering aspects of the rocket development program carried out by the Redstone div.

New York section's Physical Metallurgy Group met at New York University on Jan. 13th. Following a tour of the University's metallurgical laboratories, the group listened to George Gerard speak on Dynamic Stress-Strain Relations. Dr. Gerard, associate director of the Research div at NYU, pointed out that understanding the fundamental behavior of materials subjected to impulsive tensile or compression loading requires knowledge of both plastic wave propagation and dynamic stress-strain relations for the given material. However, the interrelation of these two factors makes analysis of either one difficult without the understanding of the other, he noted. He went on to review the interrelationships from both theoretical and experimental standpoints, and reported on the present state of knowledge in both areas. Some indication of progress was given in the form of results of a recently-completed research program in which it was determined that in plastic wave propagation the effects of strain rate are associated with the plastic component of strain only.

Lehigh Valley section's Executive Committee met on Jan. 22nd to map plans for 1960, including election of officers and meeting programs. Chairman of the Section is R. W. Sleeman; C. F. Eben has been appointed treasurer; and R. T. Renfrew, secretary. Appointments of commitee chairmen were also made; they include:

G. A. Perhac, Program and Publicity; A. T. Kaufman, Hospitality; G. K. Biemesderfer, Membership; H. J. Burnell and S. A. Ward, Student Affairs; and N. Brown, Nominating chairman. N. Brown and R. W. Sleeman were also elected Section delegate and alternate, respectively, for 1961 and 1962 .

Chicago section's technical talk on Jan. 6th brought out a total of 109 persons. Featured attraction was J. J. Bosley of U. S. Steel's Applied Research Lab, Monroeville, Pa., who spoke on *Nitrogen Quench of Experimental Blast Furnace*.

Pittsburg section's IMD group met at the city's new Hilton Hotel Jan. 21st. A record number of 70 persons were in attendance. Featured speaker was Charles Wert, University of Illinois, who spoke on *Nature of Impurities of Alloy Elements in Metals*. The meeting also marked presentation of the AIME's Robert Lansing Hardy Gold Medal to John Price Hirth, Carnegie Institute of Technology.

HEAD TABLE—Pictured above are some of the chief spokesmen at the Pittsburgh section's Jan. 21st meeting. From left to right: Joe Hollingsworth, past section chairman; Charles Wert, speaker of the evening; Eric Morgan, the Section's IMD group chairman; and R. W. Shearman, Secretary of The Metallurgical Society.

STUDENT NEWS

University of Kentucky

Activity has been high in the Norwood Mining and Metallurgical Society, the AIME student society for mining and metallurgy students at the University of Kentucky. Many meetings have been held and projects started since return to the campus last fall. More recently, a Nov. 19th get-together with the student civil engineers on campus featured a talk on radioactive metals. Speaker for the slide-illustrated talk was Louis Frank of Glenn Martin Aircraft Corp.

Attesting to the variety of programming offered by the chapter was the Dec. 10th meeting. It was here that Professor Edwards of the school's Dept. of Bacteriology spoke on *The Principle and the Uses of the Electron Microscope*. Then, just one week later, state geologist Wallace W. Hagan addressed the group on the *Geology Program of Kentucky*. As director of the state's program, he discussed the problems inherent in the $12 million project. On Jan. 7th the program consisted of two films: *Beyond Uranium and Alaska; The Frontier*.

Current Section officers are Bob Perkins, president; Jack Howard, vice president; Jim Steedly, secretary; and Jim Grey, treasurer. Jim Steedly is also chairman of the Trip Committee.

Polytechnic Inst. of Brooklyn

The Jan. 5th meeting of Brooklyn Poly's student chapter culminated a semester of planning to reactivate group interest. Committees were formed and a membership drive initiated. This drive has resulted in more than 20 applications for AIME student membership thus far. A series of bi-weekly Tuesday meetings is on the agenda, and the first of the technical meetings was held Feb. 9th. Ward Minkler of Titanium Metals Co. of America was on hand, speaking on *The Fabrication and Future of Titanium*. Paul Lane, Jr., student chapter chairman presided.

Washington State University

The AIME chapter on the Washington State University campus begins its meeting season each year with a get-together picnic. At last October's semester kick off, J. P. Spielman, Dean of Washington State's School of Engineering, spoke on the benefits derived from AIME membership. The Nov. 10th meeting of the chapter featured a talk by S. A. Duran, prof. of metallurgy at Washington State. Professor Duran is also the chapter's new faculty advisor, so his talk emphasized possible programs for future meetings. A film entitled *X-Ray Inspection* was also shown. William J. Johnson, chapter chairman, presided.

The Dec. 15th meeting presented a non-technical program. Dave Stiefhold, a graduate student member of the chapter, showed pictures taken during travels in Europe and the Middle East. On Jan. 5th, R. T. Wimber of the school's metallurgy dept. provided commentary on a movie entitled *Corrosion in Action*. Twenty persons were in attendance.

Cornell University

The Cornell Metallurgical Society's Jan. 15th meeting was highlighted by John Hawes' discussion of *Problems in the Manufacture of Copper and Brass Rod and Bar*. Mr. Hawes is with Revere Copper and Brass, Inc. A total of 27 persons attended. Refreshments were served after the talk.

Massachusetts Inst. of Tech.

A series of talks on the place for metallurgists in different industries was initiated by MIT's Student Metallurgical Society Nov. 19th. Bill Corcoran, foundry engineer at the Draper Corp., began what is hoped to be a continuing feature of the Society's meeting programs. Appropriately enough, Mr. Corcoran discussed the place and responsibilities of metallurgists in the foundry industry. At the Jan. 17th meeting of the Society, Joseph Harrington, MIT's Placement Officer, spoke on opportunities open to graduates.

Missouri School of Mines

A whopping total of 90 persons attended the Dec. 16th meeting of the Metallurgical Section of the AIME Student Chapter on the campus of Missouri School of Mines and Metallurgy. Main attraction was Clyde Krummel, chief of the production development laboratory, Rocketdyne Corp. Accounting for the large attendance was the fact that it was a triple meeting—combining student members of the American Rocket Society, Society of Automotive Engineers, and AIME.

Included in the program was a movie entitled *Road to the Stars*—portraying tests of Rocketdyne-engineered engines and Atlas missles. Then followed a 20 minute talk on possibilities for the young engineer in the rocket industry. The talk elicited a 45 minute question and answer period.

Presiding officer at the meeting was Terry Mills, chairman of the student metallurgy section on the campus.

NEW STUDENT MEMBERS

Polytechnic Inst. of Brooklyn
Brady, Paul J.
Constantine, Peter N.
Corrado, Eugene J.
Cremin, Robert W.
Erickson, John S.
Filippi, Arthur
Geffken, Robert M.
Gill, Robert E.
Hanclich, Jerald J.
Hirschhorn, Joel S.
Kotler, Gerald R.
Lanzafame, Joseph
Lieberman, Edward
Lozano, Luis J.
Maciag, Robert J.
Moore, Henry J.
Neiderman, Joel M.
Newman, Daniel F.
Niebling, Kenneth G.
Orlowsky, Kenneth J.
Schaper, Charles D.
Silverman, Harold
Snyderman, Michael H.
Swift, Robert A.
Weinstein, Paul

Colorado Schools of Mines
Fuller, John E.
Henderson, John D.
Imrie, James A.
Younts, Terry, Jr.

Lafayette College
Crewdson, Richard C.

University of Michigan
Briceno, Guillermo D.

University of Pennsylvania
Cupshalk, Stephen G.
Ekvall, Raymond A.
Ku, Roland C.

Purdue University
Tarr, Charles T.

Stanford University
Reynolds, Richard A.

Texas Western College
Correa-Nunez, Armando

University of Wisconsin
Beltran, Adrian M.
Pfau, Robert H.

Summer Metallurgical Conferences Listed

This Summer's Gordon Research Conferences, held on the Colby Junior College campus in New London, N. H., will include a number of topics of interest to metallurgists.

June 27-July 1st will be devoted to Physical Metallurgy—Relation of Structure and Properties . . . July 25-29 will see a conference on Chemistry and Metallurgy of Semiconductors . . . Aug. 1-5, Solid State Studies in Ceramics . . . and Aug. 8-12, Chemistry and Physics of Solids—Point Defects.

For more information, write Dr. W. George Parks, Director, Dept. of Chemistry, University of Rhode Island, Kingston, R. I.

DOMINIC PÁSINT

New Associate Editor Joins Magazine Staff

Dominic Pásint is the newest addition to the JOURNAL OF METALS family. "Dom" is taking over the associate editor post vacated through the resignation of Jim Burke. Jim has kicked the metallurgy traces for a more recent love—patent law. He began studying law nights at New York University in the fall of 1956, and expects to be a full-fledged patent attorney in a year. But, in order to get in some apprenticeship, he has decided to join a practicing patent attorney in New York, C. J. Elderkin. Here, he is working on Strategic Udy patents and others. Readers know him for his authoritative writings on this subject, among others, which he has done since joining the magazine in 1956.

In Dominic Pásint, JOURNAL OF METALS acquires the potential for translating many contributions to metallurgical knowledge heretofore rendered impossible. He speaks and writes German and Hungarian, in addition to English; and reads Russian, as well. He has an M.S. in mechanical engineering from the University of Technology, Budapest.

Dominic came to the US in April 1957, joining The Babcock & Wilcox Co. He was subsequently transferred to the Company's Barberton, Ohio, plant, and has acted in the capacity of performance engineer.

Authors and readers will come to know Dominic better in the contacts and the months to come.

ECPD Seeks Help in Recruiting Student Engineering Talent

The Engineers' Council for Professional Development (ECPD) is seeking individuals interested in furthering engineering education and talent in this Country. The Council needs engineers who are willing to devote time and effort as speakers and in other capacities in order that the profession may acquire the students best qualified to enter science and engineering. This recruitment is carried out on all levels: local section, state, regional, and national. If you are interested in knowing more about the program, first find out what your chapter or section is doing in this field. Should there be no guidance activity in your locality, find your state in the regions listed below, then contact the regional chairman. He will direct you to your state coordinator or nearest local chairman.

Region I: Conn., Me., Mass., N. H., R. I., Vt., Prof. E. T. Donovan, Chairman, Mechanical Engineering Dept., University of New Hampshire, Durham, N. H.

Region II: N. J., N. Y., Prof. Herbert F. Roemmele, Placement Officer, The Cooper Union, Copper Square, New York 3, N. Y.

Region III: Del., D. C., Md., Pa., D. M. Seeley, Chairman, U.S. Steel Corp., 525 William Penn Place, Pittsburgh 30, Pa.

Region IV: Ala., Fla., Ga., Miss., N.C., S.C., Tenn., Va., Harold J. Lampe, Dean of Engineering, North Carolina State College, Raleigh, N.C.

Region V: Ind., Ky., Mich., Ohio, W. Va., G. P. O'Connell, General Motors Corp., 3044 W. Grand Blvd., Detroit 2, Mich.

Region VI: Ill., Ia., Minn., Mo., Nebr., N. D., S. D., Wisc., A. B. Drought, Dean, Engineering Dept., Marquette University, 1515 W. Wisconsin Ave., Milwaukee 3, Wisc.

Region VIII: Ariz., Calif., Idaho, Mont., Nev., Ore., Utah, Wash., Americo Lazzari, Arizona Public Service Co., 4323 N. 14th Ave., Phoenix, Ariz.

Region VIII: Ark., Colo., Kan., La., N. Mex., Okla., Tex., Wyo., J. G. McGuire, Asst. to Dean of Engineering, A & M College of Texas, College Station, Tex.

Outside Continental US: Donald A. Young, Foundation of Canada Engineering Corp., Ltd., 1900 Sherbrooke St., West Montreal, Quebec, Canada.

Power Conference in Chicago Mar. 29-31

The fuel cell, our nuclear rocket program, isotopic heat and power, and magnetohydrodynamics will be among the topics under discussion during the 22nd annual American Power Conference, meeting at the Sherman Hotel, Chicago, Mar. 29-31. The three-day meeting will include approximately 95 papers and addresses covering all aspects of the power industry. The AIME is a cooperating participant in the Conference, which is principally sponsored by the Illinois Institute of Technology.

Electrochemical Society Plans May Meeting

Methods of Reducing Iron Ores is the theme of a three-day conference sponsored by the Electrothermics and Metallurgy div. of The Electrochemical Society. May 3-5 are the dates, and the LaSalle Hotel in Chicago is the place.

The Conference will bring together representatives from seven countries . . . Canada, England, France, Germany, Norway, Sweden, and the US in a series of 21 papers.

The tentative program calls for the following papers.

Tuesday morning, May 3rd: *Canada's Interest in Methods of Reducing Iron Ores* by John Convey, Department of Mines and Technical Surveys, Ottawa, Canada . . . *Economic and Process Factors Affecting the Selection of a Direct Reduction Process* by D. C. Brown, Jones & Laughlin Steel Corp., Pittsburgh . . . *Solid Fuels and Reductants for the Beneficiation and Reduction of Iron Ores* by H. U. Ross, University of Toronto . . . and *Gas Reactions in Reduction Processes* by J. Huebler, Midland Ross Corp.

The afternoon of May 3rd will see papers on *Magnetizing Roasting* by D. J. Hains, Hains Engineering Co. Ltd., Toronto . . . *How are the Blast Furnaces Doing?* by O. R. Rice, Koppers Co. Inc., Pittsburgh . . . *Performance of First Commercial H-Iron Reduction Plant*, by H. H. Stotler, Hydrocarbon Research Inc. and R. A. Lubker, Alan Wood Steel Co. . . . and *The Nu-Iron Process—A Fluidized Bed Process of Reducing Iron Ore*, by T. F. Reed, J. C. Agarwal, and E. H. Shipley, U. S. Steel Corp., Monroeville, Pa.

Wednesday morning, May 4th, the following papers are scheduled:

Reduction of Fine Iron Ore in an Agglomerating Fluidized Bed by F. M. Stephens, Jr. and B. G. Langston, Battelle Memorial Institute . . . *The Esso Research-Little Process*, by R. W. Hyde, Arthur D. Little Inc. . . . *Present Direct Reduction Research at Stora Kopparberg, Sweden* by T. O. Dormsjo, Stora Kopparberg Corp. . . . and *The R-N Process* by J. S. Breitenstein, R-N Corp.

Five papers are scheduled for the afternoon: *Reasons for the Co-current Kiln in Direct Reduction* by Horace Freeman, Freeman Corp. . . *New Agglomeration-Reduction Process for Iron Ores* by Will Mitchell, Jr., Allis-Chalmers Mfg. Co. . . *Direct Reduction Research at IRSID*, by J. Astier of IRSID . . . *The Jet Smelting Process*, by R. L. Cavanagh, Ontario Research Foundation . . . and the *New Pre-reduction Processes* by H. Walde, Demag-Elektrometallurgie.

Thursday's papers will be *Consideration of Fuel Requirements for Iron Ore Reduction by* R. Wild, British Iron and Steel Research Assn. . . *Strategic-Udy Process for Smelting Iron Ores* by M. C. Udy, Strategic-Udy Processes Inc. . . *Technical and Economic Factors to be Considered in the Electric Furnace Reduction of Iron Ores* by N. H. Keyser, Battelle Memorial Institute . . . and *Electric Smelting of Iron Ores*, by F. C. Collin, Elektrokemisk.

Address inquiries to *R. R. Rogers, Mines Branch, Dept. of Mines and Technical Surveys, 552 Booth St., Ottawa, Ontario, Canada.*

MEMBERSHIP

Proposed for Membership
Metallurgical Society of AIME

Total AIME membership on Dec. 31, 1959, was 33,378; in addition 2,332 Student Members were enrolled.

ADMISSIONS COMMITTEE

L. L. Seigle, Chairman; W. L. Brytczuk; F. B. Foley; T. D. Jones; Harold Margolin; Shadburn Marshall.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

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LOUIS S. CATES

An Appreciation

by H. DeWitt Smith

Louis Shattuck Cates, outstanding leader of this Country's copper industry, died in New York on October 29, 1959, at the age of 77. Born in Boston in 1881, he graduated from the Massachusetts Institute of Technology in 1902, and within two years of graduation found himself a job in charge of construction and development at Bingham Canyon, Utah, for the Boston Consolidated Mining Co. Here he became, successively, mining engineer, superintendent, and in 1910, general manager.

And here the shadow of Daniel C. Jackling, *Father of the Porphyries*, crossed his path. Boston Consolidated had been absorbed by the Utah Copper Co., and Cates, as acting general manager of Boston Consolidated, found himself with a good contract, but no mine to manage. He explained his predicament to Jackling, who replied, "well, you haven't shown much tendency to cooperate with us. But one of the hardest things to find is a man who works wholeheartedly in the interest of his employers. I admire you for your spunk. Stay around and we will find something for you to do." Cates stayed, and thus began a 25 year association which was invaluable to both men.

Three months later Jackling sent Cates to Ray, Ariz., for a few weeks to organize the operating staff at that property. These few weeks stretched into nine years for Cates, first as mine superintendent and then as general manager.

In 1919 Cates was called back to Utah Copper Co., first as asst. general manager, then as vice president and general manager (1923-1930). During these 20 years at Utah and Ray, he had been recognized for his operating and administrative ability in modernization and expansion of plant.

It was because of this record of performance that Cates was offered the presidency of Phelps Dodge Corp. in 1930. There he was confronted with problems ranging from mine development to refining and fabrication. The opportunities were great; he accepted the challenge, and in the next 10 years secured, expanded, and modernized the copper refineries of Nicholas Copper Co. and the copper fabricating plants of National Electric Products Corp., then added the Calumet and Arizona Mining Co. and the United Verde Copper Co. to Phelps Dodge reserves.

Mr. Cates became a member of AIME in 1904 and served the Institute for many years, first as Director (1934-1935), then as Vice President, and in 1946 as President. He became a member of the Legion of Honor in 1954, and was elected to Honorary Membership in 1955. He was recipient of the Saunders Gold Medal in 1939, and in 1955 received the Gold Medal of the Mining and Metallurgical Society for "distinguished service in mining and related industrial activities."

Mr. Cates received many honors during his long business life, including Commander of the Order of the Crown (Belgium) and Chevalier of the Legion of Honor (France). He was awarded honorary doctorates from Michigan College of Mining & Technology, the University of Arizona, and Columbia University. He was a member of the National Research Council from 1939 to 1941.

His degrees and honors he took in stride, but to the last Louis Shattuck Cates retained the ability to inspire his associates' deep personal affection and loyalty. High praise for this strong and simple leader of men.

NECROLOGY

Date Elected	Name	Date of Death
1940	Barbour, Gordon	1958
1928	Kanowitz, Samuel B.	Dec. 29, 1959
1958	Mitchell, John B.	November 1959
1940	Page, Theodore	Nov. 11, 1959
1946	Tillotson, L. A.	Dec. 27, 1959
1919	Van Gogh, F. A. A.	May 28, 1959
1940	Wardner, Wm. R., Jr.	Unknown
1899	Whitaker, Orvil R. (Legion of Honor)	Nov. 26, 1959

OBITUARIES

Ivan Pavlovich Bardin, a vice president of the Soviet Union's Academy of Sciences, died in that country recently at the age of 76. Dr. Bardin was one of Russia's leading iron and steel engineers, and was instrumental in raising the country's steel output from 4,000,000 tons prior to World War I to 60,000,000 tons last year.

He was also responsible for introducing basic oxygen steel production to the Soviet Union, and developed ways to utilize that country's low-grade ores. After graduation from Kiev Polytechnic Institute in 1910, he came to the US, working in the Chicago area for a year before returning to Russia and the accomplishments which brought him fame.

John B. Mitchell, (member 1958) died last November. Mr. Mitchell joined Jones & Laughlin Steel Corp. in 1915 as an expediter in the machine shop of Aliquippa works, then proceeded through the executive ranks before attaining the position of Executive Vice President-Production. It was from this position that he was retired in 1953 at the age of 65. At his death, Mr. Mitchell was serving as a consultant to the Swindell-Dressler Corp., Pittsburgh.

Coming Events

Mar. 9-10, Symposium on Processing of Materials for Re-entry Structures, The Mid-West Society of Aircraft Materials and Process Engineers, Dayton, Ohio.

Mar. 14-18, 16th Conference on Corrosion, National Association of Corrosion Engineers, Memorial Auditorium, Dallas, Tex.

Mar. 15-21, Third International Conference on Nondestructive Testing, Tokyo, Mar. 15-18; Osaka, Mar. 21.

March 17, Cleveland Section, NOHC, Suppliers' Night, Rockside Gardens. Subject of technical session: Basic Oxygen Process and Use of Oxygen in Open Hearths.

Mar. 29-31, 22nd American Power Conference, co-sponsored by AIME, Hotel Sherman, Chicago.

Apr. 3-8, Sixth Nuclear Engineering and Science Conference, Coliseum, New York.

Apr. 4-6, AIME 43rd National Open Hearth Steel Conference and Blast Furnace, Coke Oven, and Raw Materials Conference, Palmer House, Chicago.

Apr. 19-22, International Symposium on the Metallurgy of Plutonium, sponsored by the Societe Francaise de Metallurgie and the French Atomic Energy Commission, Grenoble, France.

Apr. 21-22, Southwest Metals and Minerals Conference, Ambassador Hotel, Los Angeles, Calif.

Apr. 25-27, Powder Metallurgy Show, sponsored by Metal Powder Industries Federation, Drake Hotel, Chicago.

Apr. 28-30, AIME Northwest Regional Conference, Sheraton Hotel, Portland, Ore.

May 2, Chicago Section, NOHC, Spring Technical Dinner Meeting, Phil Smidt's Restaurant, Hammond, Ind.

May 2-5, The Electrochemical Society, Spring national meeting, LaSalle Hotel, Chicago.

May 4, Chicago section, NOHC, Spring Dinner Meeting, Phil Smidt's Restaurant, Hammond, Ind.

May 9-11, Society for Nondestructive Testing, Second Southwest Regional Convention, The Baker Hotel, Dallas.

May 9-13, American Foundrymen's Society, National Castings Congress and Exposition, Convention Hall, Philadelphia.

May 24-26, American Society for Quality Control, Annual Convention, San Francisco.

May 25-26, AIME Symposium on Refractory Metals and Alloys, McGregor Memorial Conference Center, Wayne State University, Detroit.

May 26-27, The Metallurgical Society, New England Regional Conference on *New Developments in Metalworking*, Statler-Hilton Hotel, Boston.

June 9-10, AIME Columbium Symposium, sponsored by the Hudson-Mohawk section, Hotel Sagamore, Lake George, N. Y.

June 13-15, First International Powder Metallurgy Conference, Hotel Biltmore, New York, under joint auspices of AIME and MPIF.

July 11-12, AIME Conference on the Response of Materials to High-Velocity Deformation, Estes Park, Colo.

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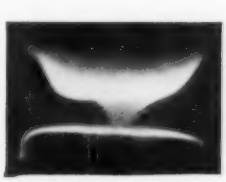
Iron carbonyl, an antiknock



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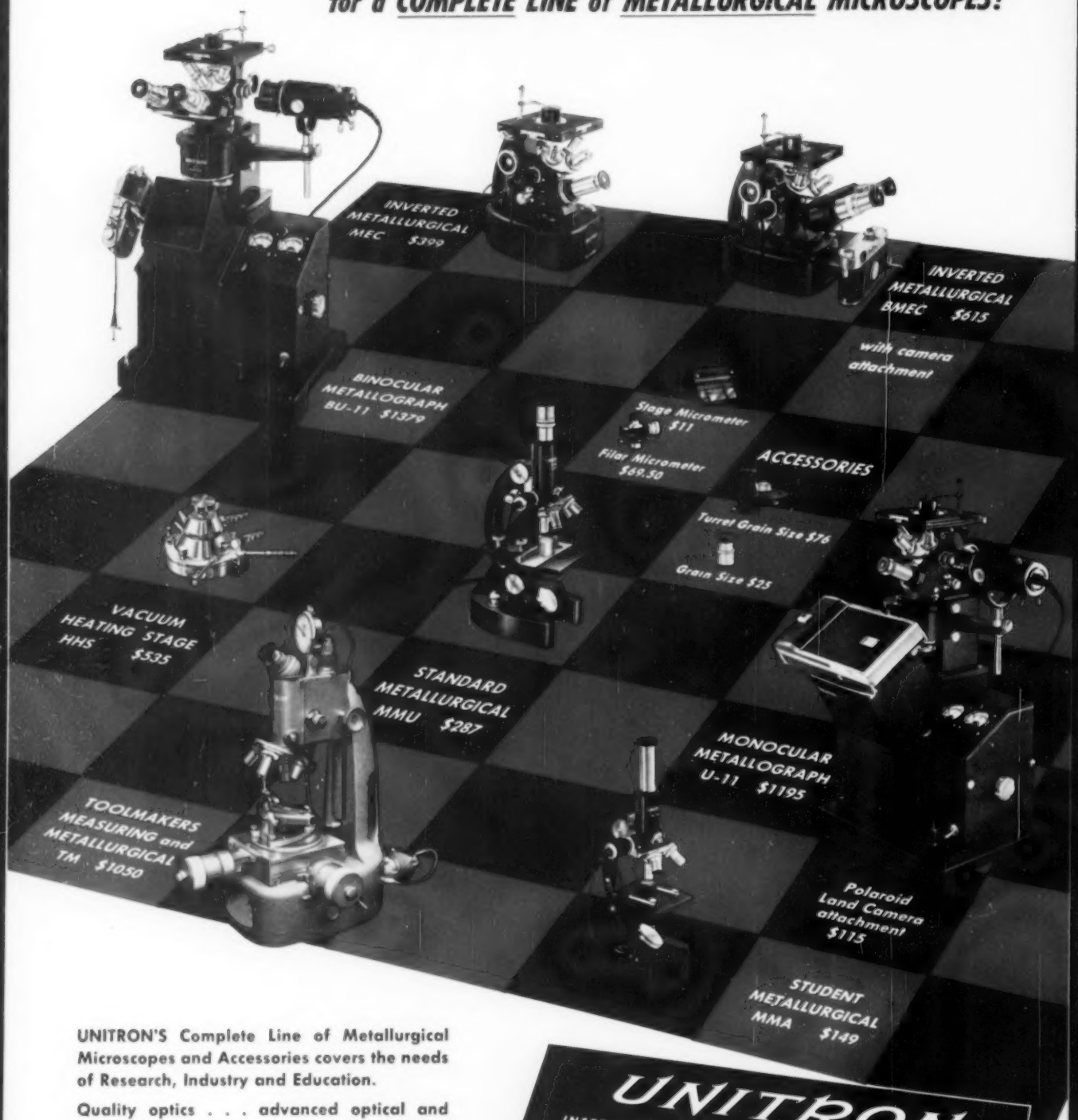

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